Environment
Canada

Saskatchewan
Environment and
Public Safety

Lake Diefenbaker and Upper South Saskatchewan River

Water Quality Study 1984-85

December, 1988

LAKE DIEFENBAKER AND UPPER SOUTH SASKATCHEWAN RIVER

WATER QUALITY STUDY

1984-85

Water Quality Branch
Saskatchewan Environment and
Public Safety

Water Quality Branch
Inland Waters Directorate
Environment Canada

December, 1988

WQ 111

89-04916/

DISCLAIMER

This report has been reviewed by the agencies involved in the study and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS i

LIST OF TABLES iv

LIST OF FIGURES vii

ACKNOWLEDGEMENTS xi

SUMMARY xii

1. INTRODUCTION 1
    - 1.1 Study Objectives and Scope 2
    - 1.2 Environmental Setting 3
    - 1.3 Previous Studies 5
    - 1.4 Lake Diefenbaker Water Use Concerns 8

2. HYDROLOGY 14
    - 2.1 South Saskatchewan and Red Deer Rivers 14
    - 2.2 Lake Diefenbaker Water Levels 16

3. RIVER CHEMISTRY 22
    - 3.1 Assessment Methodology 22
        - 3.1.1 Sampling Sites 22
        - 3.1.2 Sampling Schedule and Field Methods 22
        - 3.1.3 Parameters 24
    - 3.2 Results and Discussion 27
        - 3.2.1 Nutrients 27
        - 3.2.2 Phosphorus Loading to Lake Diefenbaker 41
        - 3.2.3 Major Ions and Physical Parameters 62

TABLE OF CONTENTS (continued)

Page

4. LAKE CHEMISTRY 77

4.1 Assessment Methodology 77

4.1.1 Sampling Sites 77

4.1.2 Sampling Schedule and Field Methods 78

4.1.3 Parameters 79

4.2 Results and Discussion 81

4.2.1 Dissolved Oxygen and Temperature 81

4.2.2 Nutrients and Related Parameters 90

4.2.3 Major Ions and Physical Parameters 108

5. EUTROPHICATION 111

5.1 Assessment Methodology 111

5.1.1 Nutrient Limitations to Plant Growth 113

5.1.2 Model for Eutrophication Indicator Predictions 117

5.2 Results and Discussion 124

5.2.1 Trophic Indicator Predictions 124

5.2.2 Present Lake Trophic State 127

5.2.3 Critical Loadings for Phosphorus 129

6. LAKE BIOLOGY 133

6.1 Phytoplankton 133

6.1.1 Species Composition 133

6.2 Bacteria 150

TABLE OF CONTENTS (continued)

Page

7. NEAR-SHORE STUDY 160

7.1 Assessment Methodology 160

7.1.1 Sampling Sites 160

7.1.2 Sampling Schedule and Field Methods 161

7.1.3 Parameters 161

7.2 Results and Discussion 162

7.2.1 Field Measurements 162

7.2.2 Nutrients 163

7.2.3 Phytoplankton 167

7.2.4 Bacteria 172

8. CONCLUSIONS AND RECOMMENDATIONS 182

REFERENCES 192

LIST OF TABLES

Page

1. Estimated Water Withdrawals from Lake Diefenbaker 9

2. River Sampling Sites, 1984-85 23

3. River Monitoring Details, 1984-85 25

4. A Comparison of Replicate Samples for Lemsford 29

5. Estimates of Annual Phosphorus Loading into Lake Diefenbaker Calculated from Monthly Monitoring Data (1975-1985) 48

6. Monthly Mean Phosphorus Loading into Lake Diefenbaker (1975-1985) 52

7. Summary of Study Period and Historic Results for Major Ions and Physical Parameters, River Monitoring Stations 63

8. Saskatchewan Water Quality Objectives for Surface Waters and Municipal Drinking Water Supplies (pH and Major Ions) 76

9. Lake Diefenbaker Mid-Lake Sampling Sites, 1984-85 77

10. Lake Monitoring Details, 1984-85 79

11. Lake Diefenbaker Inter-Lab Quality Assurance Program: Comparison of Provincial Lab Data to Environment Canada Lab Using Major Parameters (1984-85) 91

12. A Comparison of Replicate Samples for Lake Diefenbaker at Saskatchewan Landing for Selected Parameters, 1984-85 93

13. Mean TKN Concentrations for Lake Diefenbaker - in mg/L 94

14. Mean NO_3 + NO_2 Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L 96

15. Mean Total Phosphorus Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L 100

16. Mean DOC Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L 104

17. Mean Chlorophyll "a" Concentrations for the Lake Diefenbaker Study (1984-85) - in ug/L 105

18. Mean Secchi Depths for the Lake Diefenbaker Study (1984-85) - in metres 108

LIST OF TABLES (continued)

Page

19. Mean, Maximum and Minimum Concentrations of Physical Parameters and Major Ions, Lake Diefenbaker Stations, 1984-85 110

20. The Inorganic Nitrogen/Ortho-phosphate Ratios for the Lake Diefenbaker Mid-Lake Sampling Stations, 1984-85 115

21. Summary of Physical Characteristics of Lake Diefenbaker Showing the Five Lake Areas and the Whole Lake, 1984-85 118

22. Summary of the Data Used to Develop the Relationships in Equations 5-1 to 5-3 123

23. Summary of the Statistical Parameters for the Model Formulae 125

24. Summary of the Measured and Predicted [P] and [chl a] for the Saskatchewan Landing Station from 1975 to 1985 127

25. The Probabilities of the Lake Areas Being in a Trophic Category Based on the Parameter Levels Averaged for the Study Period, 1984-85 129

26. Loading of P that Would Maintain the [P] = 20 mg/m^3 130

27. Phytoplankton Genera and Species Observed in Lake Diefenbaker, 1984-85 134

28. Total Number of Phytoplankton Species Observed Within Each Phylum at Each Sampling Station in Lake Diefenbaker, 1984-85 146

29. Total Relative (per cent) Volumetric Composition of Phytoplankton Phyla Within Lake Diefenbaker, 1984-85 149

30. Lake Diefenbaker Near-Shore Sampling Sites - August, 1984 160

31. Lake Diefenbaker Near-Shore Study Field Measurements - August, 1984 162

32. Mean Values for Nitrogen Parameters Analyzed for the Lake Diefenbaker Near-Shore Study - August, 1984 165

33. Mean Values for Phosphorus Parameters Analyzed for the Lake Diefenbaker Near-Shore Study - August, 1984 166

34. Phytoplankton Genera and Species Observed in Lake Diefenbaker Near-Shore Study - August, 1984 169

LIST OF TABLES (continued)

Page

35. Total Number of Phytoplankton Species Observed Within Each Phylum at Each Near-Shore Sampling Station in Lake Diefenbaker - August, 1984 171

36. Total Relative (per cent) Volumetric Composition of Phytoplankton Phyla at Each Near-Shore Station in Lake Diefenbaker - August 13-15, 1984 172

LIST OF FIGURES

Page

1. Lake Diefenbaker and the Upper South Saskatchewan River - Study Setting and Sampling Sites, 1984-85 4

2. Mean Monthly Discharges for the South Saskatchewan and Red Deer Rivers, 1984 and 1985 15

3. Detailed Hydrograph for the South Saskatchewan River at Highway 41, 1984-1985 17

4. Detailed Hydrograph for the Red Deer River at Bindloss, 1984-1985 18

5. Mean Monthly Lake Elevations for Lake Diefenbaker, 1984 and 1985 19

6. Detailed Hydrograph for the South Saskatchewan River below Gardiner Dam (Measured at Saskatoon), 1984-85 21

7. Nitrogen Data for Lemsford Site, 1985 31

8. Nitrogen Data for Gardiner Site, 1985 33

9. Comparison of DN for Gardiner and Lemsford Sites, 1985 34

10. Phosphorus Data for Lemsford Site 36

11. TSS for Lemsford Site 37

12. TP Data for Gardiner Site 39

13. Comparison of DP, PP and TP for Gardiner Site, 1985 40

14. Comparison of TP for Lemsford and Gardiner Sites, 1985 41

15. TOC, POC and DOC Data for Lemsford, 1985 43

16. Gardiner Site Carbon Data, 1985 44

17. Annual Phosphorus Loading into Lake Diefenbaker, 1975-1985 49

18. Monthly Mean Total Phosphorus Loading into Lake Diefenbaker, 1975-1985 53

19. Monthly Mean Dissolved Phosphorus Loading into Lake Diefenbaker, 1975-1985 55

20. Mean Daily Total Phosphorus Loading at Lemsford Ferry, 1985 58

21. Mean Seasonal Dissolved Phosphorus Loading at Lemsford Ferry, 1985 60

LIST OF FIGURES (continued)

Page

22. Spatial Plot of Study Period (circles) and Period of Record (triangles) Mean and Range for pH and Specific Conductance 68

23. Spatial Plot of Study Period (circles) and Period of Record (triangles) Mean and Range for Total Alkalinity and Total Hardness 69

24. Best Second Order Seasonal Fit for pH at Stations Above Lake Diefenbaker, 1984-85 (top) and at Leader and Outlook, 1978-85 (bottom) 71

25. Best Second Order Seasonal Fit for Specific Conductance at Stations Above Lake Diefenbaker, 1984-85 (top) and at Leader and Outlook, 1978-85 (bottom) 72

26. Best Second Order Seasonal Fit for Total Alkalinity at Stations Above Lake Diefenbaker, 1984-85 (top) and at Leader and Outlook, 1978-85 (bottom) 73

27. Best Second Order Seasonal Fit for Total Hardness at Stations Above Lake Diefenbaker, 1984-85 (top) and at Leader and Outlook, 1978-85 (bottom) 74

28. Depth-Time Isopleths of Dissolved Oxygen Concentrations (upper) and Temperature (lower) for Lake Diefenbaker Station 1, 1984-85 82

29. Depth-Time Isopleths of Dissolved Oxygen (Left) and Temperature (Right) for Lake Diefenbaker Station 2, 1984-85 83

30. Depth-Time Isopleths of Dissolved Oxygen (Left) and Temperature (Right) for Lake Diefenbaker Station 3, 1984-85 85

31. Depth-Time Isopleths of Dissolved Oxygen (Left) and Temperature (Right) for Lake Diefenbaker Station 4, 1984-85 86

32. Depth-Time Isopleths of Dissolved Oxygen (Left) and Temperature (Right) for Lake Diefenbaker Station 5, 1984-85 87

33. Depth-Time Isopleths of Dissolved Oxygen (Left) and Temperature (Right) for Lake Diefenbaker Station 6, 1984-85 89

34. Lake Diefenbaker Study Data for Dissolved Nitrogen (Means/Run) - Stations 1-3 (Top) and Stations 4-6 (Bottom) 97

35. Lake Diefenbaker Study Data for Particulate Nitrogen (Means/Run) - Stations 1-3 (Top) and Stations 4-6 (Bottom) 98

LIST OF FIGURES (continued)

Page

36. Lake Diefenbaker Study Data for Total Nitrogen (Means/Run) - Stations 1-3 (Top) and Stations 4-6 (Bottom) 99

37. Lake Diefenbaker Study Data for Total Phosphorus (Means/Run) - Stations 1-3 (Top) and Stations 4-6 (Bottom) 101

38. Lake Diefenbaker Study Data for Dissolved Phosphorus (Means/Run) - Stations 1-3 (Top) and Stations 4-6 (Bottom) 102

39. Seasonal Variations in Secchi Depths for Lake Diefenbaker at Station 4, 1984-85 107

40. The Inorganic [N]/Ortho [P] Ratios for the Study Period at Saskatchewan Landing, Riverhurst and Danielson 116

41. The Mean Summer Phosphorus Concentrations for the Five Lake Areas Compared to the OECD (1982) Model and The 95% Confidence Limits 120

42. The Mean Summer Chlorophyll "a" Concentrations for the Five Lake Areas Compared to the OECD (1982) Model and Its 95% Confidence Limits 121

43. The Mean Summer Secchi Disk Depths for the Five Lake Areas Compared to the OECD (1982) model and Its 95% Confidence Limits 122

44. Seasonal Total Phytoplankton Species Diversity vs Mean Seasonal Biovolume Observed at Lake Diefenbaker, 1984-1985 138

45. Seasonal Species Abundance Observed Within the Phylums Bacillariophyta, Chlorophyta and Cyanophyta at Lake Diefenbaker, 1984-1985 139

46. Seasonal Relative (per cent) Volumetric Abundance of Chlorophyta, Cyanophyta and Bacillariophyta in Lake Diefenbaker, 1984-1985 142

47. Overall Mean Algal Biovolume and Density Observed Within Each Phylum at Lake Diefenbaker, 1984-1985 143

48. Spatial Trends Regarding Total Phytoplankton Species Abundance and Mean Total Algal Biovolume Observed at Lake Diefenbaker, 1984-1985 148

49. Total Coliform Densities at Mid-Lake Stations on Lake Diefenbaker During Summer Periods of 1984-85 153

LIST OF FIGURES (continued)

Page

50. Fecal Coliform Densities at Mid-Lake Stations on Lake Diefenbaker During Summer Periods of 1984-85 154

51. Fecal Streptococci Densities at Mid-Lake Stations on Lake Diefenbaker During Summer Periods of 1984-85 155

52. Indicator Bacteria (TC, FC, FS) Densities at Leader Bridge (Hwy. 21) on the South Saskatchewan River During Summer Periods of 1984-85 159

53. Diurnal Dissolved Oxygen Concentration (mg/L) and Temperature (°C) at Lake Diefenbaker (Station No. 9) - August 14-16, 1985 (as indicated by continuous D.O. recorder) 164

54. Total Coliform Densities at Near-Shore Stations on Lake Diefenbaker -August 13-15, 1984 174

55. Fecal Coliform Densities at Near-Shore Stations on Lake Diefenbaker -August 13-15, 1984 175

56. Fecal Streptococci Densities at Near-Shore Stations on Lake Diefenbaker - August 13-15, 1984 176

ACKNOWLEDGEMENTS

The field work involved in collection of data presented in this report was conducted by staff of the Water Quality Branch, Saskatchewan Environment and Public Safety and the Water Quality Branch, Inland Waters Directorate, Environment Canada. The report was prepared by K. Lauten, R. Ruggles, E. Stockerl, K. Weagle and R. Zitta of Saskatchewan Environment and Public Safety and R. Crosley and D. Gregor of Environment Canada. R. Zitta was responsible for overall report compilation and editing. The review comments of Environment Canada staff were of much assistance in preparing the report in its final form.

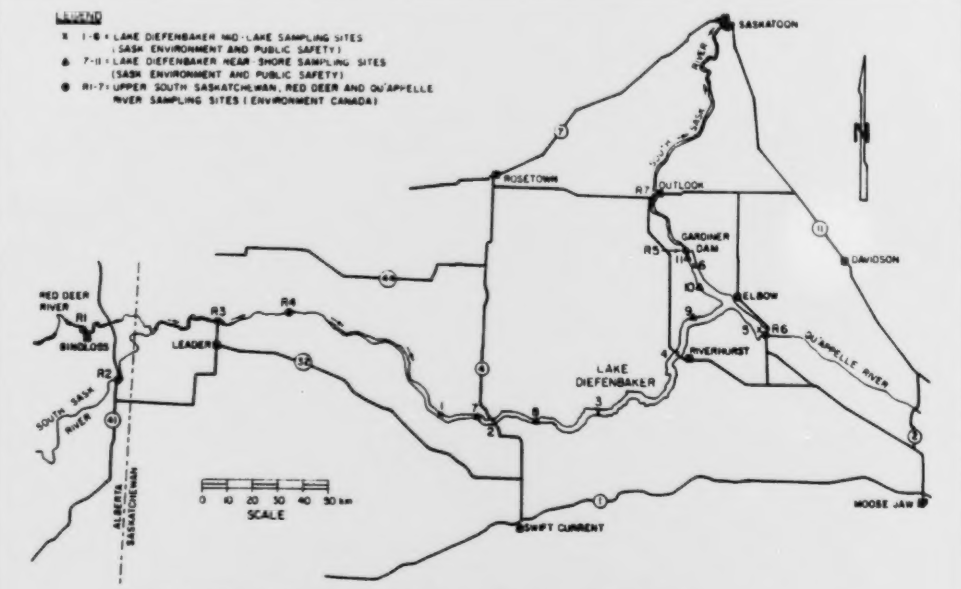
The able assistance and support provided by: M. Heisler, Saskatchewan Environment and Public Safety, Regina; D. Munro and W. Gummer, Environment Canada, Regina; T. Yuzyk, Environment Canada, Ottawa; E. Ongley, NWRI, Burlington; P. Tones, Saskatchewan Research Council, Saskatoon; and W. Rast, USGS, Austin, Texas, is acknowledged.

Our appreciation is also extended to J. Kudelis and L. Gergely, Administration and Communications Branch, Saskatchewan Environment and Public Safety, for their assistance in typing this document.

Summary

INTRODUCTION

Lake Diefenbaker and the upper South Saskatchewan River east of the Alberta border form the largest supply of good quality water in southern Saskatchewan. The South Saskatchewan River is a broad, swift-flowing river which derives over 90% of its flow from snowmelt and rainfall in the Rocky Mountains. Lake Diefenbaker, created by the completion of the Gardiner and Qu'Appelle Dams in 1967, is the major storage reservoir on the river. The reservoir measures 225 kilometres in length and has a total storage capacity of 9.4 billion cubic metres. These waterbodies serve as supplies for a wide range of uses including power generation, irrigation, municipal and industrial water supplies, recreation, wildlife habitat, sport and commercial fishing and flood control.


LEGEND
× 1-6 : LAKE DIEFENBAKER MID-LAKE SAMPLING SITES (SASK ENVIRONMENT AND PUBLIC SAFETY)
▲ 7-11 : LAKE DIEFENBAKER NEAR-SHORE SAMPLING SITES (SASK ENVIRONMENT AND PUBLIC SAFETY)
● R1-7 : UPPER SOUTH SASKATCHEWAN, RED DEER AND QU'APPELLE RIVER SAMPLING SITES (ENVIRONMENT CANADA)
SASKATOON
SOUTH SASK RIVER
N
ROSETOWN
R7
OUTLOOK
11
7
GARDINER DAM
R5
11
6
10
ELBOW
DAVIDSON
44
RED DEER RIVER
R1
SINDLOSS
R3
R4
LEADER
9
5
R6
QU'APPELLE RIVER
4
RIVERHURST
R2
52
4
LAKE DIEFENBAKER
SOUTH SASK RIVER
41
1
7
8
3
2
2
0 10 20 30 40 50 km
SCALE
ALBERTA
SASKATCHEWAN
1
MOOSE JAW
SWIFT CURRENT

LAKE DIEFENBAKER AND THE UPPER SOUTH SASKATCHEWAN RIVER
STUDY SETTING AND SAMPLING SITES, 1984 - 1985

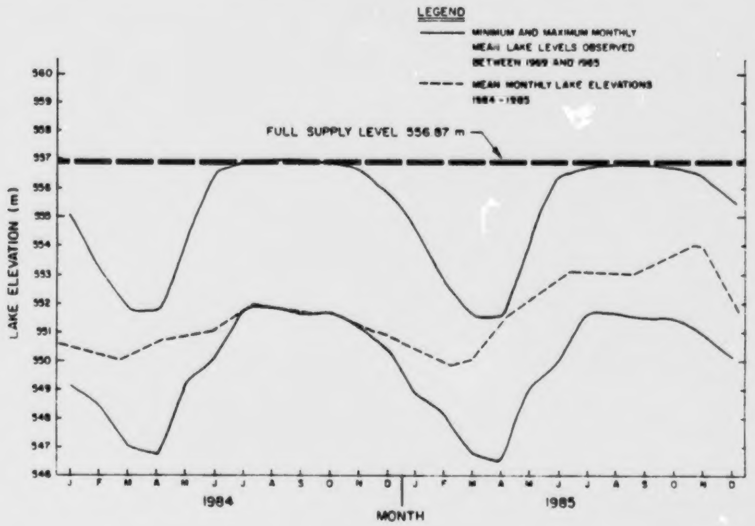
Water entering Saskatchewan from Alberta via the South Saskatchewan River system presently receives point and non-point inputs from municipal, industrial and agricultural sources. Potential problems related to nutrients and salinity are of greatest concern for the Saskatchewan portion of the basin and Lake Diefenbaker, in particular.

In 1984-85 a comprehensive water quality study of the upper South Saskatchewan River and Lake Diefenbaker was conducted jointly by the Water Quality Branch of Saskatchewan Environment and Public Safety and the Water Quality Branch of Inland Waters Directorate, Conservation and Protection, Environment Canada. The goal of the study was to provide a reliable information base for water managers responsible for the long-term protection of these waterbodies. Specific study objectives were:

1. To characterize the physical, chemical and biological properties of these waterbodies.
2. To quantitatively describe the trophic status of Lake Diefenbaker.
3. To assess the acceptability of existing water quality relevant to present and foreseeable uses.

KEY STUDY RESULTS

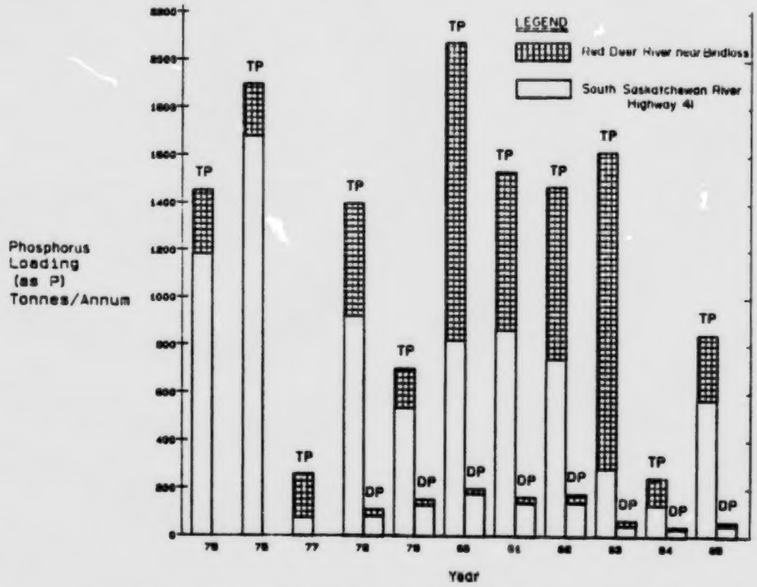
The South Saskatchewan River flow rates during 1984-85 were far below the long-term mean. In 1984, the prairie snowmelt peak was all but absent in the river system. Spring runoff was close to normal in 1985, however, the later mountain snowmelt was well below normal. Lake Diefenbaker water levels in 1984 were the lowest since 1969 for the months of August through November. The lake levels were higher in 1985 for the summer period but remained well below the full supply level of the reservoir.



MEAN MONTHLY LAKE ELEVATIONS FOR LAKE DIEFENBAKER, 1984 AND 1985

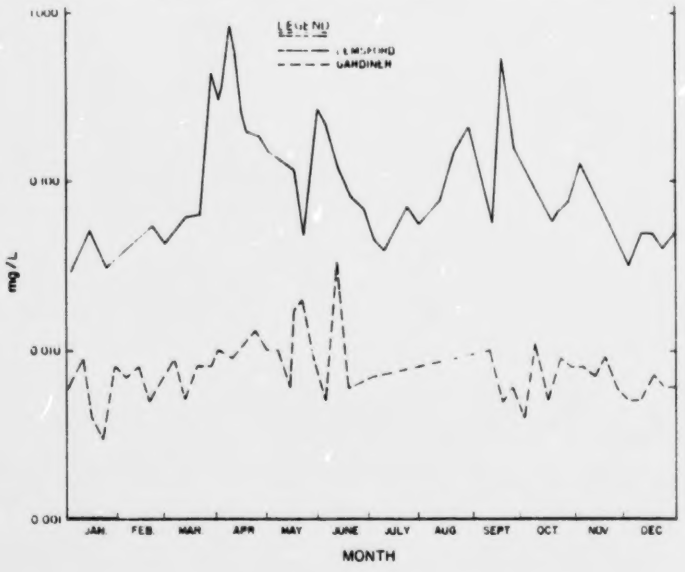
River Chemistry

Seven river sampling locations were established for the 1984-85 study. Monitoring of the four sites upstream of Lake Diefenbaker was designed to examine variability of loading to the lake while the stations at Gardiner Dam, Qu'Appelle River at Highway 19 and South Saskatchewan River at Outlook examined output from the reservoir. Monthly long-term monitoring data from the South Saskatchewan and Red Deer Rivers and more intensive study data acquired at Lemsford Ferry and Gardiner Dam were used to provide nutrient loading information for Lake Diefenbaker. From the historical data the average combined total phosphorus (TP) load to the lake was determined to be 1,229 tonnes per year. The TP load for the study period (1984-85) was determined to be 814 tonnes.



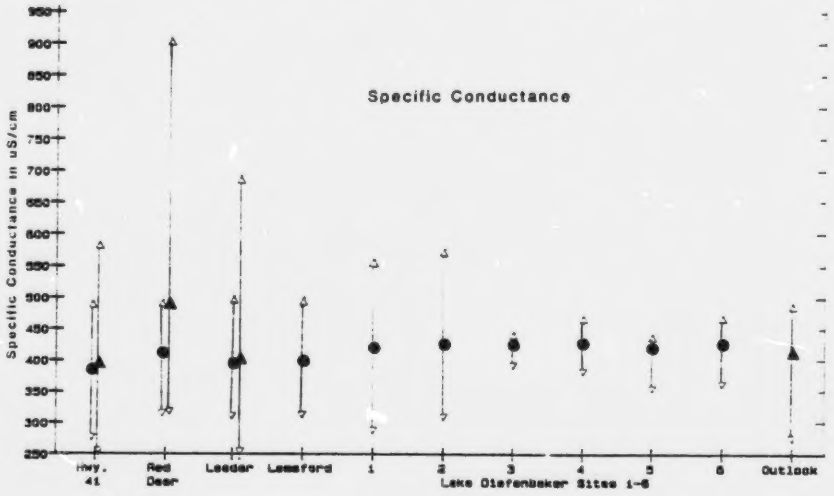
ANNUAL PHOSPHORUS LOADING INTO LAKE DIEFENBAKER, 1975 - 1985

Approximately 89% of the TP load entering Lake Diefenbaker is particulate phosphorus. At Gardiner Dam dissolved phosphorus is the dominant form throughout most of the year. The fact that Lake Diefenbaker is acting as a sink for nutrients flowing in from the South Saskatchewan River is evident by the very low levels of nitrogen and phosphorus measured at the outflow from Gardiner Dam. Total phosphorus concentrations at Gardiner Dam were about ten times less than at Lemsford.



COMPARISON OF TP FOR LEMSFORD AND GARDINER SITES, 1985

Four locations on the Red Deer and South Saskatchewan Rivers were monitored for major ions and physical parameters during the study. Results showed that the Red Deer River tended to be more highly mineralized then the South Saskatchewan. However, little change in mean concentrations of major ions occurred in the 330 kilometre reach between Leader and Outlook, which includes Lake Diefenbaker. The pattern of dominance of the major ions (calcium, magnesium, sodium, potassium, bicarbonate, sulphate and chloride) also didn't change between these sites.



SPATIAL PLOT OF STUDY PERIOD (CIRCLES) AND PERIOD OF RECORD (TRIANGLES) MEAN AND RANGE FOR SPECIFIC CONDUCTANCE.

Specific conductance is an indicator of the total amount of dissolved substances in the water.

Lake Chemistry and Biology

Six sampling stations were established at approximately equal distances along the length of Lake Diefenbaker. For most of the year, water temperatures did not vary with depth at each station. During July and August, water temperatures decreased with depth but distinct thermoclines (layer of water where temperatures decline rapidly) were not observed. Dissolved oxygen concentrations were high and quite uniform with depth for most of the year. Lower dissolved oxygen levels were measured near the lake bottom in late summer when lake temperatures were highest and in late winter when the lake was ice-covered.

Eutrophication is the response of aquatic ecosystems to enrichment by nutrients, particularly phosphorus and nitrogen. The increase in lake fertility can cause symptoms such as algae blooms, nuisance growths of rooted aquatic plants, low dissolved oxygen levels and unpleasant taste and odour of the water. In Lake Diefenbaker, phosphorous was determined to be the nutrient limiting algae growth. The trophic response of Lake Diefenbaker to river phosphorus loadings was evaluated using the OECD (1982)[1] eutrophication model.

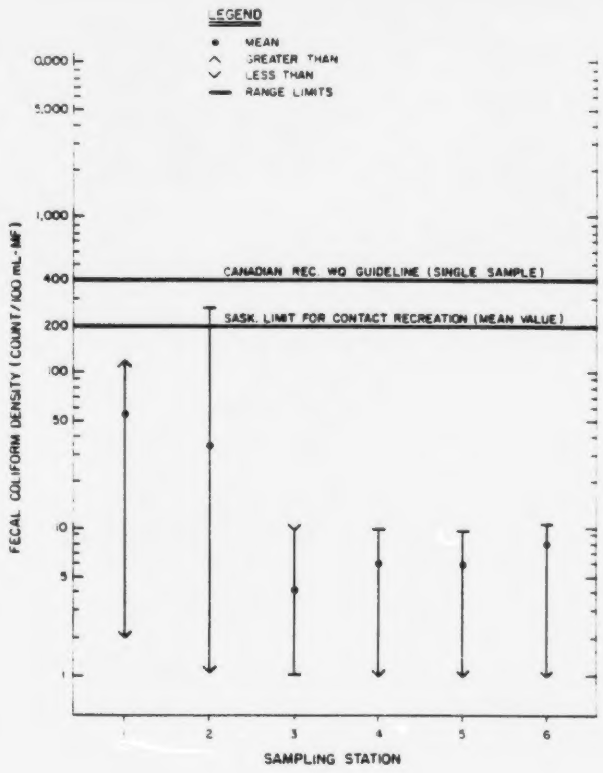
Monitoring for nutrients in Lake Diefenbaker revealed that the concentrations were quite low, although the lake does respond to the nutrient loads received from the South Saskatchewan River system. Nutrient levels were consistently higher in the shallower upstream locations than in the deep water areas further downstream. The concentrations of phosphorus and chlorophyll "a" indicated most areas of the lake were mesotrophic (moderately productive). The Danielson reach near Gardiner Dam is considered oligotrophic (low in nutrients and productivity).

---

1. OECD (1982) Eutrophication of waters: Monitoring, Assessment and Control. Organization for Economic Co-operation and Development. Paris, France.

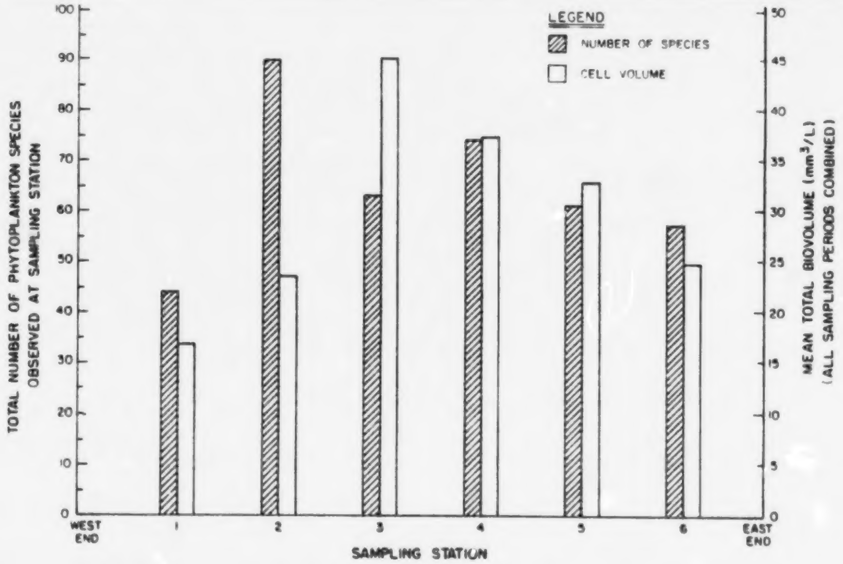
The OECD (1982) model was used to estimate phosphorus loadings necessary to maintain a mesotrophic status in the upstream portion of the lake near Saskatchewan Landing Provincial Park. Based on average annual flows in the South Saskatchewan and Red Deer Rivers, the critical phosphorus loading at the Alberta-Saskatchewan border was estimated to be 130 tonnes per year. The Prairie Provinces Water Board is considering a draft Water Quality Indicator for total phosphorus loading at the border of 285 tonnes per year to prevent excessive phosphorus loading to the whole lake. The present database is not sufficient to make a final recommendation on a phosphorus loading limit for Lake Diefenbaker at this time.

The coliform group of bacteria were monitored in Lake Diefenbaker to evaluate the sanitary status of the lake for recreational use. Mean total and fecal coliform densities in the off-shore portion of the lake were low and indicative of water with little fecal contamination. Five near-shore beach areas were monitored on one day in the summer. Fecal coliform levels in some samples collected near Saskatchewan Landing and Coteau beaches exceeded the provincial water quality objectives for contact recreation, indicating potential localized contamination caused by suspended bottom materials (due to wave action) or from livestock or human-related activities. Bacteria densities at other beach areas were low. There are no large scale sources of fecal contamination (e.g. sewage) in any portion of the basin studied.



FECAL COLIFORM DENSITIES AT MID-LAKE STATIONS
ON LAKE DIEFENBAKER DURING SUMMER PERIODS OF
1984 - 1985

Phytoplankton (algae) are the major primary producers in the lake ecosystem and can be used as an indicator of lake trophic status. Over 100 algal species were observed in the lake during the study. The greatest diversity of species occurred within the green algae group. Blue-green algae accounted for the majority of the algal biovolume measured, however the overall algal abundance indicated mesotrophic to oligotrophic conditions in the lake.



SPATIAL TRENDS REGARDING TOTAL PHYTOPLANKTON SPECIES ABUNDANCE AND MEAN TOTAL ALGAL BIOVOLUME OBSERVED AT LAKE DIEFENBAKER (ALL SAMPLING PERIODS COMBINED) 1984-1985

Water Quality and Water Use

The results of the 1984-85 Lake Diefenbaker and upper South Saskatchewan River study were assessed in terms of the Saskatchewan Surface Water Quality Objectives and the Canadian Water Quality Guidelines published by the Canadian Council of Resource and Environment Ministers. Overall, the results showed the quality of these waterbodies is satisfactory for present and foreseeable uses.

The concentrations of major ions did not exceed the Canadian or Saskatchewan guidelines and objectives for most sensitive uses including drinking water supply, irrigation and livestock watering.

Dissolved oxygen levels in Lake Diefenbaker generally exceeded the Saskatchewan objective of 5.0 mg/L for protection of fish and aquatic life. Low oxygen levels measured near the lake bottom on some occasions are not considered a concern for fish populations.

The densities of total and fecal coliform bacteria measured at all off-shore and most near-shore sites on Lake Diefenbaker met the Saskatchewan objectives for contact and non-contact recreational use.

The trophic status of Lake Diefenbaker ranged from mesotrophic to oligotrophic, based on in-lake measurements of total phosphorus, chlorophyll a and phytoplankton. Maintenance of at least mesotrophic or better conditions in all areas of the lake will ensure avoidance of problems such as nuisance algal blooms, deoxygenation and unpleasant taste and odour in the long-term.

Recommendations

1. It is recommended that any new or modified developments in the basin upstream not be undertaken in a manner that would result in a net increase in phosphorus loading to Lake Diefenbaker.
2. Research to determine the proportion of the particulate phosphorus load in the South Saskatchewan River which is biologically available should be undertaken. This would help evaluate the significance of the total phosphorous loading to eutrophication in Lake Diefenbaker.
3. It is evident that total phosphorus loading to Lake Diefenbaker is already high. Negotiations should be held with Canada, Alberta and Saskatchewan to prevent further increases in TP loading and to examine feasible options for protecting the long-term quality of Lake Diefenbaker.
4. Future refinement of the OECD (1982) eutrophication model should include phosphorus loadings from all major sources, including runoff from surrounding land and atmospheric deposition.
5. Additional bacteriological monitoring of selected beach areas on Lake Diefenbaker should be undertaken during the recreation season to determine if objectives for contact recreational use are being achieved.
6. The present nutrient-related database for Lake Diefenbaker and the South Saskatchewan River should be augmented by three more years of data collection and targeted at more typical hydrological conditions.

1. INTRODUCTION

Water is a precious commodity in semi-arid southern Saskatchewan. Most creeks and some rivers in this region flow for only a brief period each year during spring runoff. In most years, water becomes scarce by late June. In drought years such as 1984, even spring runoff may fail to materialize.

Lake Diefenbaker and the upper South Saskatchewan River form the largest supply of good quality water in southern Saskatchewan. Originating in the Rocky Mountains, the South Saskatchewan River is a combination of three mountain streams, the Red Deer, Bow and Oldman Rivers. After supplying water to many communities and vast irrigation projects in southern Alberta, the Bow and Oldman Rivers join upstream of the Alberta-Saskatchewan boundary to form the South Saskatchewan River. The Red Deer River joins the South Saskatchewan a few miles east of the provincial boundary. Lake Diefenbaker, created by the completion of the Gardiner and Qu'Appelle River Dams in 1967, is the major storage reservoir on the South Saskatchewan River.

Water entering the province from Alberta via the South Saskatchewan River system presently receives significant point and non-point inputs from municipal, industrial and agricultural sources. Potential problems related to nutrients and salinity are of greatest concern for the Saskatchewan portion of the basin and Lake Diefenbaker, in particular. Comprehensive water quality studies have not been conducted in the Saskatchewan portion of the basin and the existing database is quite limited. In order to contribute to the protection and management of Lake Diefenbaker and the South Saskatchewan River within Saskatchewan as projected increases in water use and withdrawal occur, an intensive short duration study was undertaken in 1984-85.

1.1 Study Objectives and Scope

The goal of the 1984-85 study was to provide a reliable information base for water managers responsible for the long-term protection of Lake Diefenbaker and the Saskatchewan portion of the upper South Saskatchewan River.

The specific objectives were:

1. To characterize the physical, chemical and biological properties of these waterbodies (this includes consideration of temporal and spatial variabilities);
2. To quantitatively describe the trophic condition of Lake Diefenbaker; and
3. To assess the acceptability of existing water quality relevant to present and foreseeable water uses.

The Lake Diefenbaker and upper South Saskatchewan River Study was undertaken by the Water Quality Branch of Saskatchewan Environment and Public Safety and the Water Quality Branch of Inland Waters Directorate, Environment Canada.

1.2 Environmental Setting

The study area encompassed the South Saskatchewan River, Red Deer River and Lake Diefenbaker from the Prairie Provinces Water Board (PPWB) river stations within Alberta to the station near Outlook below Gardiner Dam. Figure 1 illustrates the study setting and also shows the sampling sites for the project.

The South Saskatchewan River Basin traverses approximately 700 kilometres over two major physiographic regions, the Alberta Plateau and the Saskatchewan Plains. The Alberta Plateau is elevated 100 to 150 metres above the Saskatchewan Plains, the division between the two steppes being marked by the Missouri Coteau Escarpment which crosses the South Saskatchewan river Valley near Riverhurst. Landforms in the basin area are generally gently rolling glacial plains.

The soils within the Saskatchewan portion of the basin are primarily of the brown chernozemic type with the exception of the complex regosolic soils in the river valley itself (Richards and Fung, 1969). The river valley within the Alberta Plateau above Riverhurst is a deep, broad and strongly eroded meltwater channel cut 60 to 150 metres into the glacial deposits and underlying bedrock. Below Riverhurst the valley is shallower and generally narrower.

The climate in the study area is semi-arid (cold steppe) receiving approximately 300 to 350 millimetres of precipitation

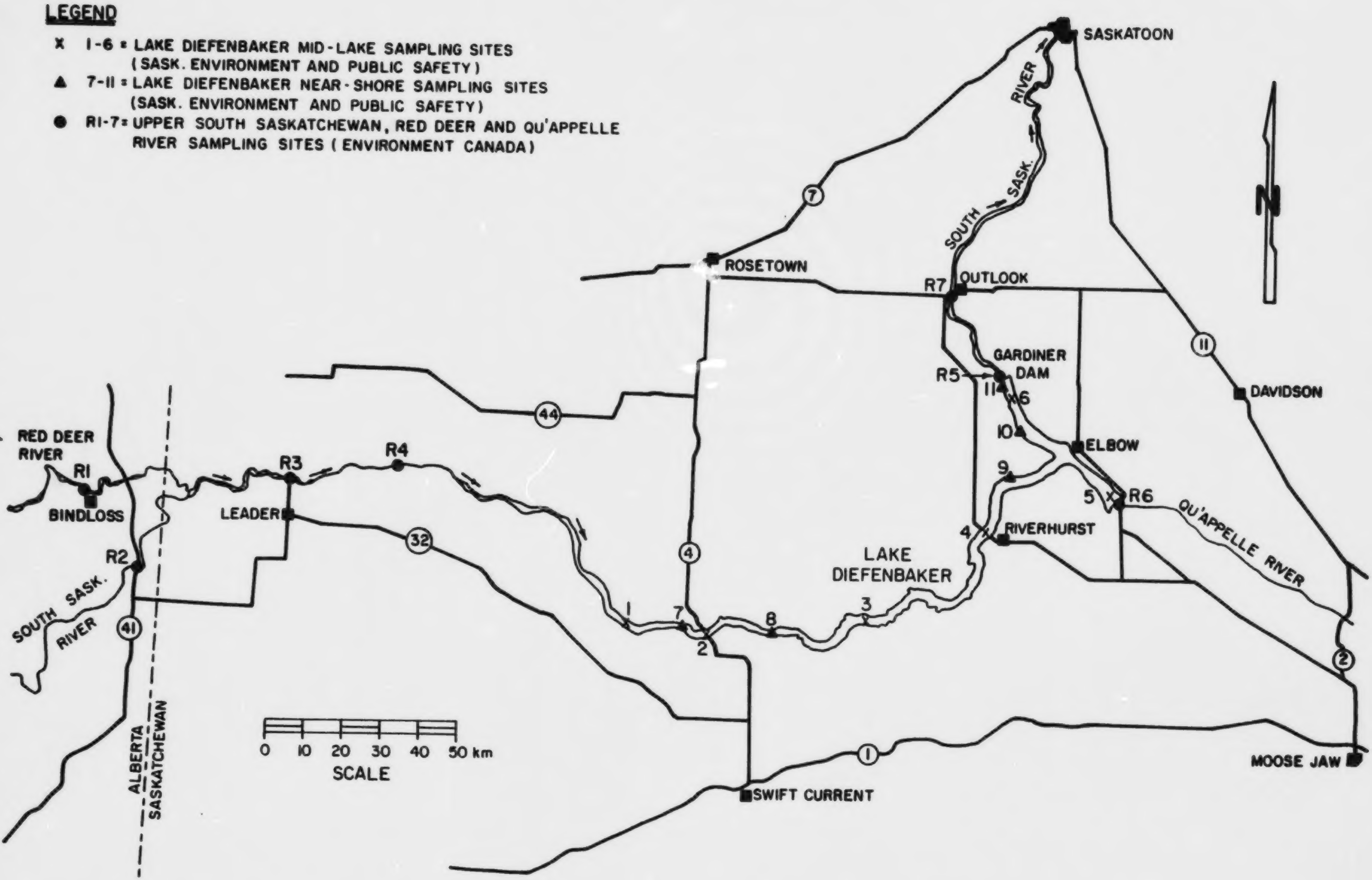

LEGEND
x 1-6 = LAKE DIEFENBAKER MID-LAKE SAMPLING SITES (SASK. ENVIRONMENT AND PUBLIC SAFETY)
▲ 7-11 = LAKE DIEFENBAKER NEAR-SHORE SAMPLING SITES (SASK. ENVIRONMENT AND PUBLIC SAFETY)
● R1-7 = UPPER SOUTH SASKATCHEWAN, RED DEER AND QU'APPELLE RIVER SAMPLING SITES (ENVIRONMENT CANADA)
N
SASKATOON
SOUTH SASK. RIVER
7
ROSETOWN
R7
OUTLOOK
11
DAVIDSON
GARDINER DAM
R5
11
6
10
ELBOW
44
RED DEER RIVER
R1
BINDLOSS
R3
R4
9
5
R6
QU'APPELLE RIVER
LEADER
32
4
RIVERHURST
LAKE DIEFENBAKER
R2
SOUTH SASK. RIVER
41
1
7
2
8
3
2
0 10 20 30 40 50 km
SCALE
ALBERTA
SASKATCHEWAN
1
SWIFT CURRENT
MOOSE JAW

Figure I : LAKE DIEFENBAKER AND THE UPPER SOUTH SASKATCHEWAN RIVER STUDY SETTING AND SAMPLING SITES, 1984 - 1985

annually. Crop and range lands are the prevalent forms of vegetation within the Saskatchewan portion of the drainage basin.

The South Saskatchewan River is a broad, swift-flowing river which derives over 90% of its flow from snowmelt and rainfall in the Rocky Mountains. The drainage basin within Saskatchewan does not contribute significantly to the streamflow because of limited precipitation and numerous internal drainage features. The South Saskatchewan River drains approximately 136,000 kilometres (km) of land above Gardiner Dam, however, 80% of this area is located outside of the province.

Lake Diefenbaker is a large multi-purpose reservoir on the South Saskatchewan River. The construction phase of the South Saskatchewan River Project began in 1958 and took almost 9 years to complete. The inundation of Lake Diefenbaker created a reservoir measuring 225 km in length with a shoreline of 760 km when at full supply level. The reservoir covers an area of 43,000 hectares with a total storage of 9.4 billion cubic metres (m^3) and a usable storage of 3.9 billion m^3.

1.3 Previous Studies

Saskatchewan Environment and Public Safety has been monitoring water quality at Leader and Outlook on the South Saskatchewan River, and at Saskatchewan Landing, Goodwin Subdivision, Riverhurst Ferry, Danielson Provincial Park and Douglas Provincial Park on Lake Diefenbaker for the last decade. The quantities of data vary considerably by station and parameter.

Environment Canada maintains water quality and quantity monitoring stations for the Prairie Provinces Water Board (PPWB) on the Red Deer River near Bindloss and the South Saskatchewan River at Highway 41 (both sites in Alberta). Since 1974, monthly water quality monitoring has been conducted at these stations for a wide range of parameters. Updated statistical and graphical summaries of the results are published annually; the most recent is the 1974 to 1985 summary (PPWB 1987). The Committee on Water Quality of the PPWB is presently developing site-specific water quality indicators for each river at the border.

An inter-governmental steering committee studying Regina-Moose Jaw water supply alternatives initiated a water quality monitoring program on the Qu'Appelle system which also had two sample stations on Lake Diefenbaker. Samples were collected quarterly from July 1981 to September 1982 for limited chemical and bacteriological analysis by the Saskatchewan Research Council.

The Buffalo Pound Water Treatment Plant Laboratory has also collected and analyzed water samples from Lake Diefenbaker at Riverhurst Ferry. Although the amount of data is small the results allow a preliminary inter-laboratory comparison.

Although there has never been an intensive water quality study of Lake Diefenbaker, a number of other related studies have been done. The subjects of these studies include: recreation strategy (Hilderman Witty Crosby Hanna & Associates 1984), recreational fishing (Chen 1983), limnology and fisheries from 1967 to 1969 (Royer 1972), evaluation of walleye, whitefish and lake trout stocks (Royer 1972; Smith 1974) and reservoir sedimentation (Yuzyk 1983). A limited amount of information is available on hydrology, ground water and bank stability. The hydrology of the lake and the operation of Gardiner Dam were recently reviewed by Woodvine (1983) and Banga (1983).

In addition to these studies a large quantity of information is available on the South Saskatchewan River Basin in Alberta. The South Saskatchewan River Basin Eutrophication Control Study (SSRBECS) had three objectives: to quantify significant nutrient sources in the basin, to define the relationship between nutrients and aquatic plant growth and to predict the impact of point source nutrient control on plant growth. The study began in 1979 and a report of the nutrient and water chemistry results is available (Charlton _et_ _al_. 1981), (Cross _et_ _al_, 1984).

The SSRBECS provides a large volume of data on nutrients and other water quality parameters in the South Saskatchewan River in Alberta. Unfortunately, the Red Deer River was not part of the SSRBECS and consequently findings of the Alberta report are of limited value for the present study.

1.4 Lake Diefenbaker Water Use Concerns

1.4.1 Introduction

Lake Diefenbaker and the South Saskatchewan River serve as supplies for a wide range of uses including power generation, irrigation, municipal and industrial water supplies, recreation, wildlife habitat, sport and commercial fishing and flood control. Careful management is necessary to maintain a balance between availability and use under growing pressure.

Water use falls into two main categories, instream and offstream. The major offstream uses are irrigation and municipal and industrial supply. It is anticipated that withdrawals for these uses will increase dramatically in the future. Table 1 shows the current estimated water withdrawals from Lake Diefenbaker (1985 data) and the prospective long-term requirements (South Saskatchewan River Basin Study, 1986).

Instream water uses include: power generation, recreation and fish and wildlife habitat. All these uses must be controlled so that any one use will not detrimentally affect any other. Many activities such as dam construction, land development, agricultural runoff and discharges of industrial and municipal wastes can have a significant impact on the water quality of a water body such as Lake Diefenbaker.

Table 1

Estimated Water Withdrawals From Lake Diefenbaker
(from South Saskatchewan River Basin Study, 1986)

Type of Withdrawal	Current Annual Requirement (1985) (Dam^3)	Prospective Long-Term Annual Requirement (Dam^3)
Downstream Releases	1,340,000	1,340,000
Municipal	1,000	5,000
Industrial	6,000	15,000
Qu'Appelle Diversion	142,000	230,000
SSEWS Project	50,000	75,000
Lake Diefenbaker Irrigation	110,000	580,000
Evaporation from Lake Diefenbaker	236,000	236,000
TOTAL	1,885,000	2,481,000
Million dam^3 (approx.)	1.9	2.5

Dam^3 = cubic decametres

The Saskatchewan Environment and Public Safety water quality management policy is to conserve water and to protect, maintain and improve its quality for the protection of public health and, within economic limits, for the following purposes:

(a) preservation and protection of water supplies;
(b) encouragement of economic development;
(c) preservation of aesthetic values; and
(d) preservation of fish and wildlife (Saskatchewan Environment, 1983).

The Department has established specific surface water quality objectives as a means by which it can assess the quality of water and municipal and industrial wastewater effluents. The objectives represent water quality suitable for most uses either through direct use or prepared for use by an economically practial degree of treatment. These general objectives are supplemented by the Municipal Drinking Water Quality Objectives (Saskatchewan Environment, 1980) that apply to municipal and other communal waterworks that serve the public.

1.4.2 Drinking Water Quality

As noted in Table 1, the current annual requirement for municipal drinking water withdrawal from Lake Diefenbaker is about 1,000 cubic decametres (dam^3) and this is expected to rise in the future. All of this water has to be treated to make it fit for human consumption.

The most important requirements for a surface water supply are:

1. That it contain no organisms which cause disease (bacteriological quality).
2. That it have satisfactory chemical quality.
3. That it be clear, colourless and free from taste and odours.

Harnessing the South Saskatchewan River has assured an adequate supply of water for municipal and industrial growth at Regina, Moose Jaw and in the area served by the Saskatoon Southeast Water Supply System. In the future, water delivery systems based on the project will likely be expanded to other areas of Saskatchewan.

1.4.3 Irrigation

Southern Saskatchewan's semi-arid climate makes it a natural area for irrigation wherever water is available and soil and topography are suitable. Crop production can be increased and stabilized through irrigation.

The suitability of water for irrigation is determined by concentrations of dissolved salts, trace substances and pathogens. The most common problems resulting from the use of poor quality water for irrigation are accumulation of salts in the root zone and loss of soil permeability because of excess sodium.

Lake Diefenbaker, as part of the South Saskatchewan River Irrigation Project, has not yet reached its potential as a water supply for irrigation. The transition from dry land farming to the use of irrigation has been a very gradual process. Nevertheless, it is expected that use of irrigation will continue to grow so that by the year 2030 almost 200,000 hectares will be irrigated in the vicinity of Lake Diefenbaker and the South Saskatchewan River.

1.4.4 Recreation and Other Water Uses

Lake Diefenbaker and the South Saskatchewan River provide opportunities for high quality water-based recreation centered around three provincial parks, six regional parks and five resort subdivisions.

The recreation potential of Lake Diefenbaker in an otherwise arid region has only begun to materialize. Recreation facilities are expected to expand and the lake's value as a resort area will increase. The closeness of Lake Diefenbaker to major population centres and travel routes and pressure on other southern Saskatchewan resort areas gives it outstanding potential.

The 187,500 kilowatt Coteau Creek generating station has been in operation on Lake Diefenbaker since December, 1968. It produces an average of 775 million kilowatt hours of energy each year. By storing the high summer flows of the river for power production in the winter, the majority of this energy is available in the high energy demand months from November to March.

The Saskatchewan Water Corporation presently operates the Water Supply Utility which provides water from Lake Diefenbaker for a variety of uses. This utility employs the Saskatoon South East Water System (SSEWS), comprised of 5 reservoirs and interconnecting canals and pipelines, to deliver approximately 16 million m^3 of water each year. Uses along the SSEWS include irrigation, municipal water supplies, recreation, waterfowl projects and industrial developments.

The formation of Lake Diefenbaker converted about 42,000 hectares of the South Saskatchewan River valley into a lake. This resulted in significant changes for the wildlife and fish of the region.

The habitat for upland animals including deer, birds, rodents and predators was flooded while the habitat for fish and waterfowl was expanded.

Saskatchewan Parks and Renewable Resources carried out fish stocking programs in 1969 and 1975. Millions of walleye, whitefish and lake trout were introduced making Lake Diefenbaker a popular fishing spot. In addition to the stocked fish, northern pike, perch, sauger and goldeye, which are native to the river, have quickly populated the reservoir. A commercial fishery has developed on Lake Diefenbaker since 1976 and is based mainly on a substantial whitefish population.

2. HYDROLOGY

2.1 South Saskatchewan and Red Deer Rivers

The mean monthly discharges for the period of record for the South Saskatchewan River (19 years) and for the Red Deer River (25 years) are plotted in Figure 2. The mean monthly discharges for each of the rivers for the study years, 1984 and 1985, are also shown in this figure. The flows for the South Saskatchewan River during the study were far below the long-term mean. Especially noticeable were the extremely low flows in this river during April and May, 1984 - normally months of high flow - with the flow declining to only 40 m^3/sec during May.

Generally, a bimodal distribution is observed in the annual hydrographs for each of these river systems. This is evident in the long-term data for the Red Deer River but the dominance of the mountain snowmelt peak in the long-term hydrograph of the South Saskatchewan River system masks the peak normally associated with prairie snowmelt. In 1984, the prairie snowmelt peak was all but absent in both river systems. A minor broad peak occurred in February and March, 1984, associated with early chinook-induced melting, after which no significant additional snowfall occurred to contribute to a true spring melt. Spring runoff in both basins in 1985 was close to normal; however, the later mountain snowmelt in the South Saskatchewan basin was well below normal. The flow measured for the Red Deer River at Bindloss after May, 1985 was very low for this time of year.

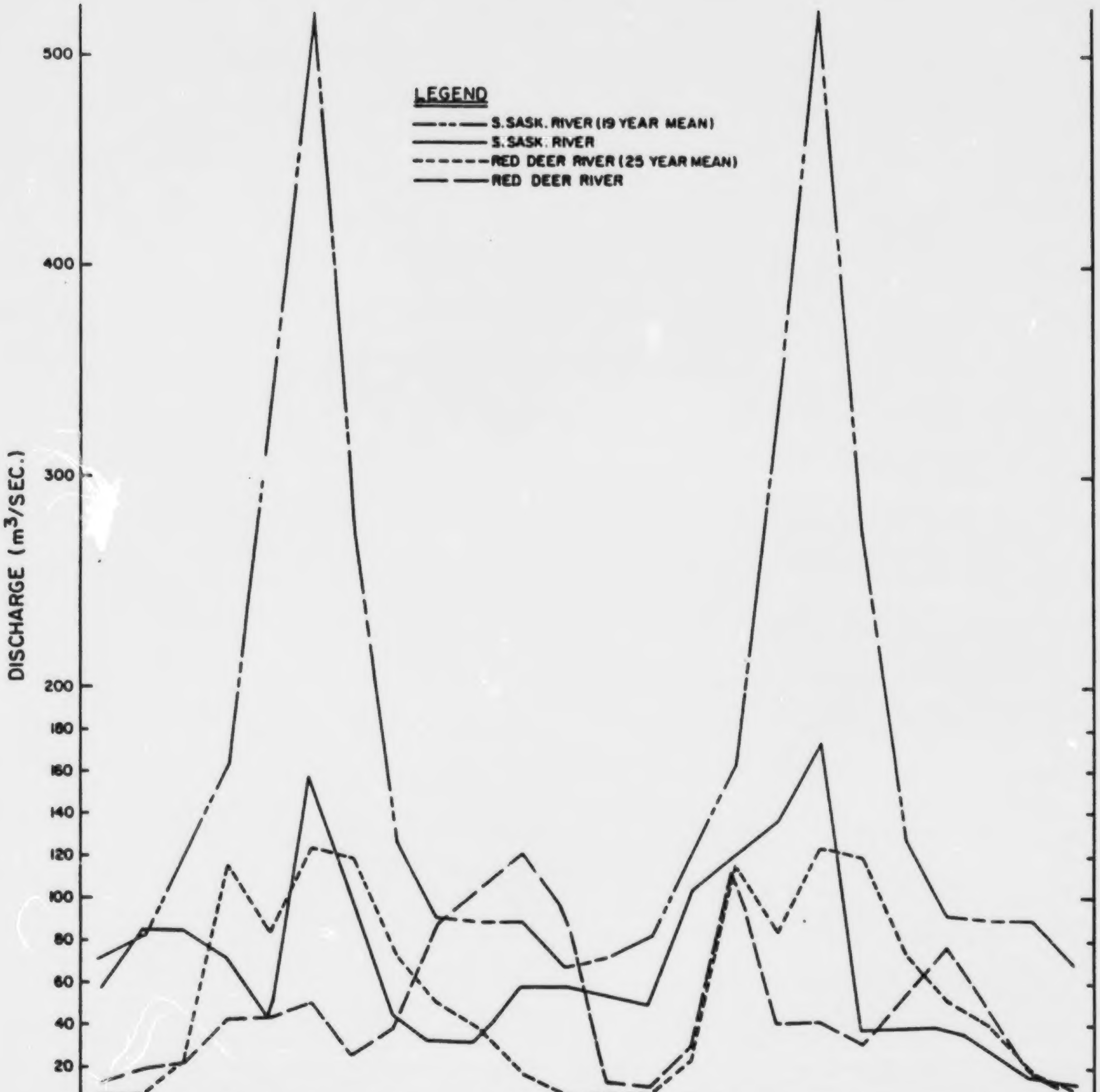


Figure 2 : MEAN MONTHLY DISCHARGES FOR THE SOUTH SASKATCHEWAN AND RED DEER RIVERS, 1984 AND 1985

The detailed hydrographs for the two rivers for 1984 and 1985 are shown in Figures 3 and 4. The complexity in the hydrographs is not unusual as the basins are large, partially regulated and are subject to isolated heavy rain storms affecting only portions of the basin during the summer months. Chinooks cause rapid melting of snow at times other than the spring melt. The Red Deer River had been relatively unregulated until late 1984 when the Gleniffer Reservoir was completed and filled. Since completion, the reservoir has increased naturally occurring low winter flows at the provincial boundary.

2.2 Lake Diefenbaker Water Levels

The mean monthly lake elevations for Lake Diefenbaker for 1984 and 1985 are shown in Figure 5 along with the mean monthly minimum and maximum elevations observed between 1969 and 1985. It is evident from this figure that lake levels in 1984 were the lowest since 1969 for the months of August through November. The lake levels were higher in 1985 for the summer and fall periods but remained well below the full supply level of the reservoir.

The reduced flows in the two primary tributaries to the lake resulted in extensive drawdown of the reservoir during 1984 and 1985. This drawdown would have been even more severe had the pattern up to March, 1985 continued; however, at that time the limited availability of snow in the mountains was recognized and

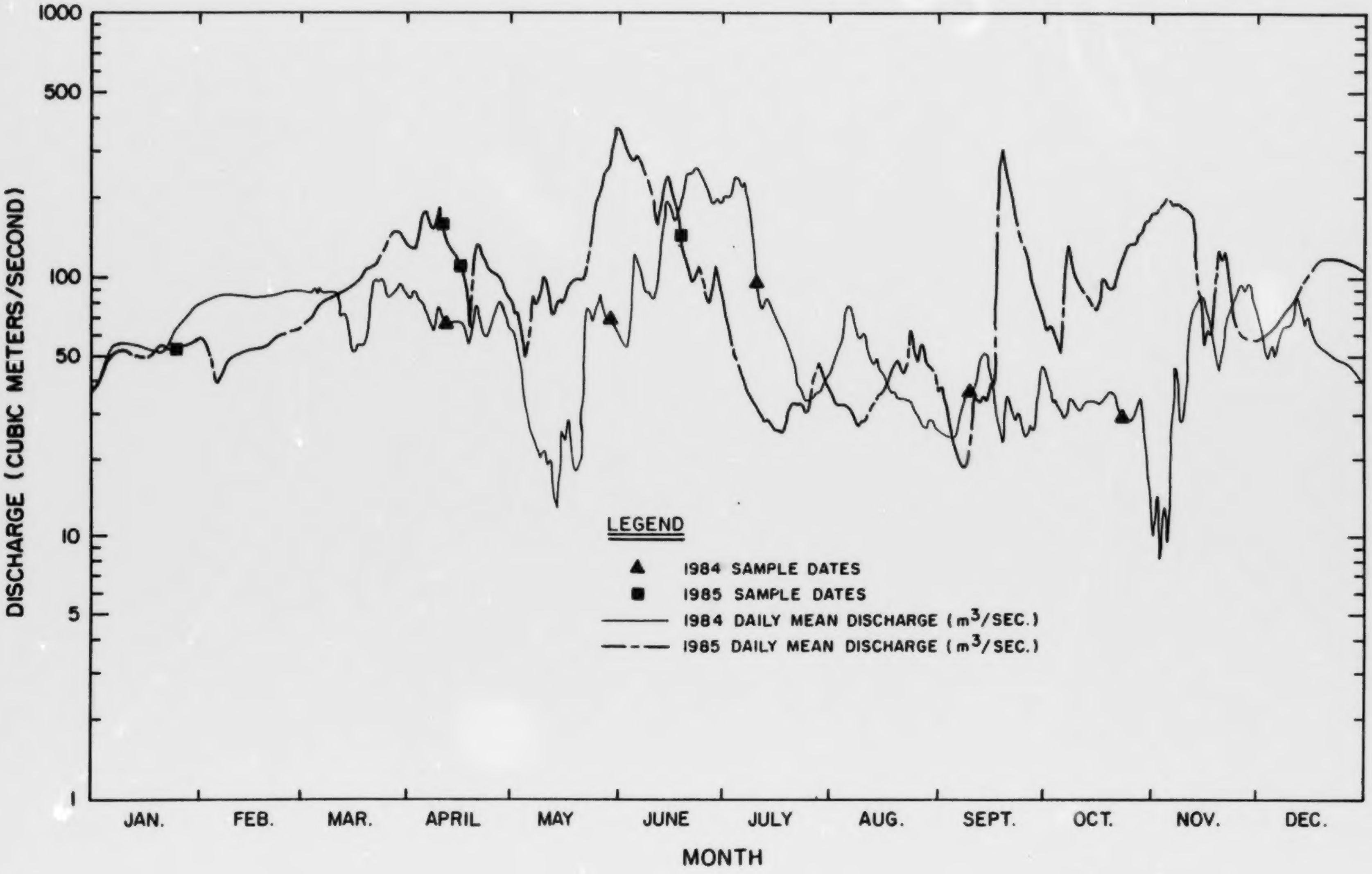


Figure 3 : DETAILED HYDROGRAPH FOR THE SOUTH SASKATCHEWAN RIVER AT HIGHWAY 41
1984 - 1985

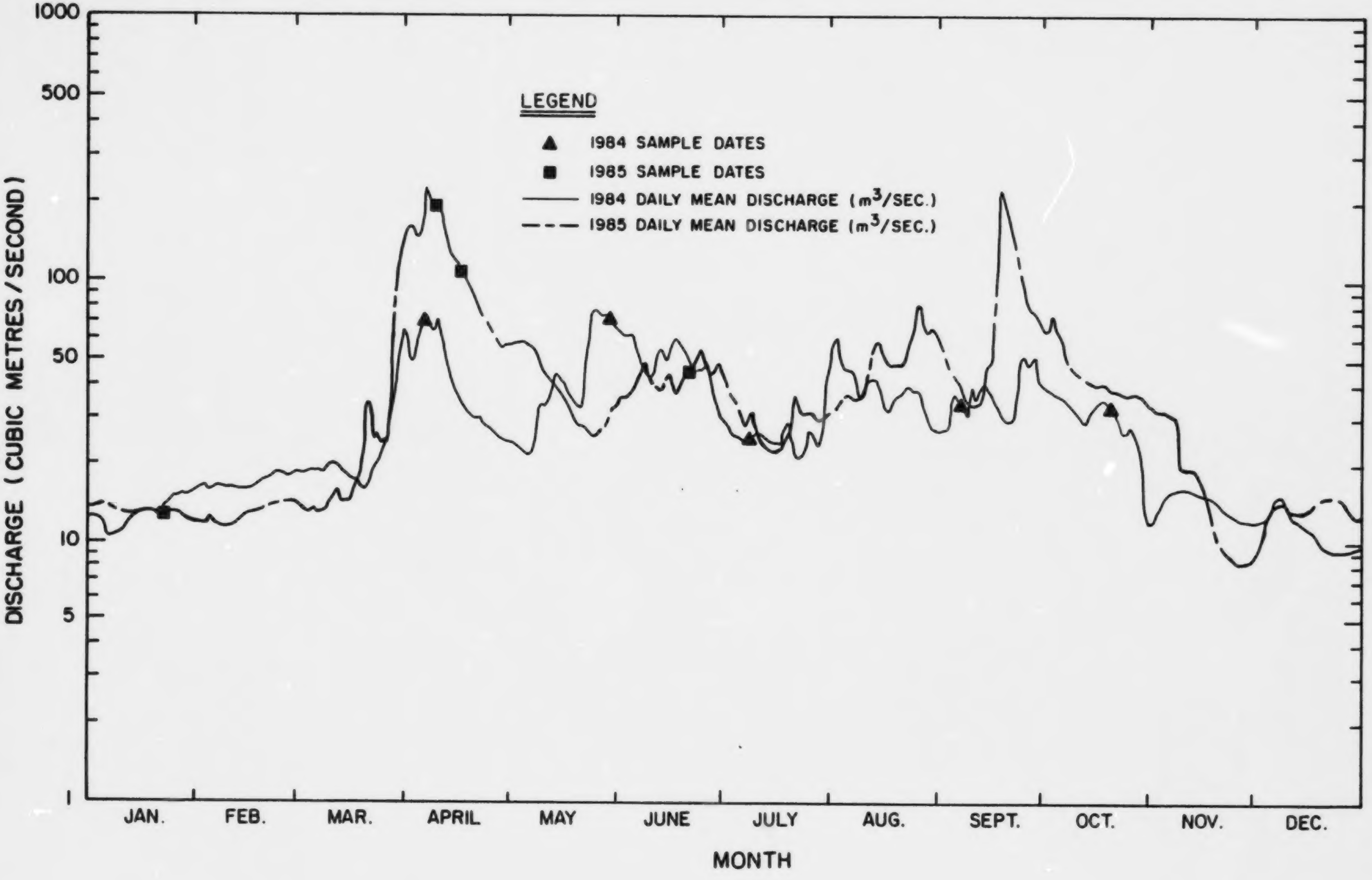


Figure 4 : DETAILED HYDROGRAPH FOR THE RED DEER RIVER AT BINDLOSS , 1984 - 1985

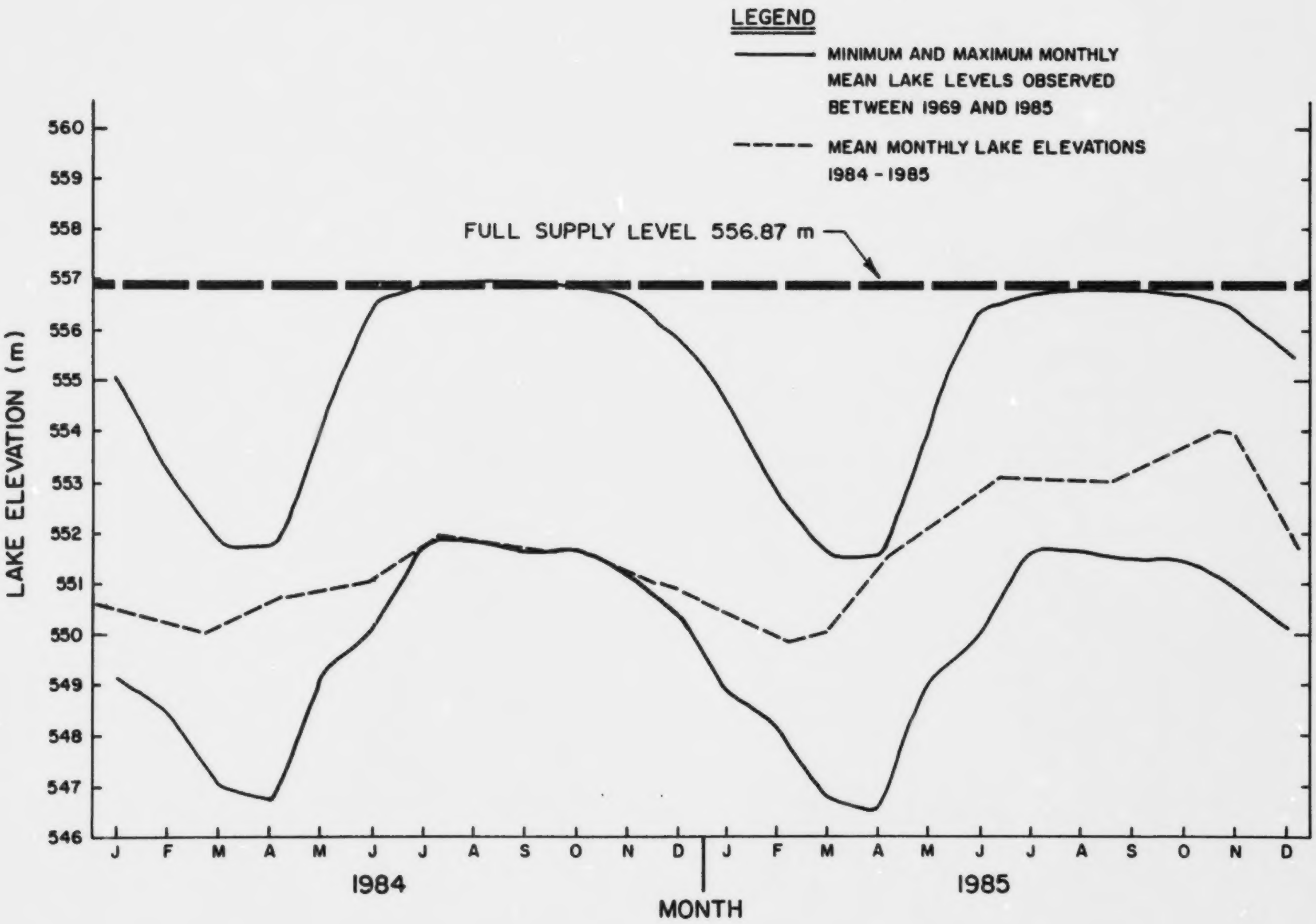


Figure 5 : MEAN MONTHLY LAKE ELEVATIONS FOR LAKE DIEFENBAKER, 1984 AND 1985

mean daily flow from the reservoir at Gardiner Dam was reduced from about 120 m^3/sec to approximately 50 m^3/sec. Flows were again increased in April and May (see Figure 6) but were reduced to the minimum permitted (daily mean discharge of approximately 42 m^3/sec) by mid-June. These minimal flows were maintained until mid-November.

Lake Diefenbaker provides water to the Coteau Creek Power Plant at Gardiner Dam which operates as a peaking plant so that large releases of water occur on an almost daily cycle. The reservoir is usually drawn down over the winter to help meet the power demands in Saskatchewan which are highest during the winter months and then the reservoir is refilled by the influx of water during the prairie and mountain snowmelt events. This refilling did not occur in 1984 and 1985 with the result that reservoir levels were as much as 8 metres below full supply level. This problem was compounded by the fact that an estimated 5% of the reservoir's volume is lost annually through evaporation. Additional details regarding the hydrology of the lake and operation of Gardiner Dam are available in Woodvine (1983) and Banga (1983).

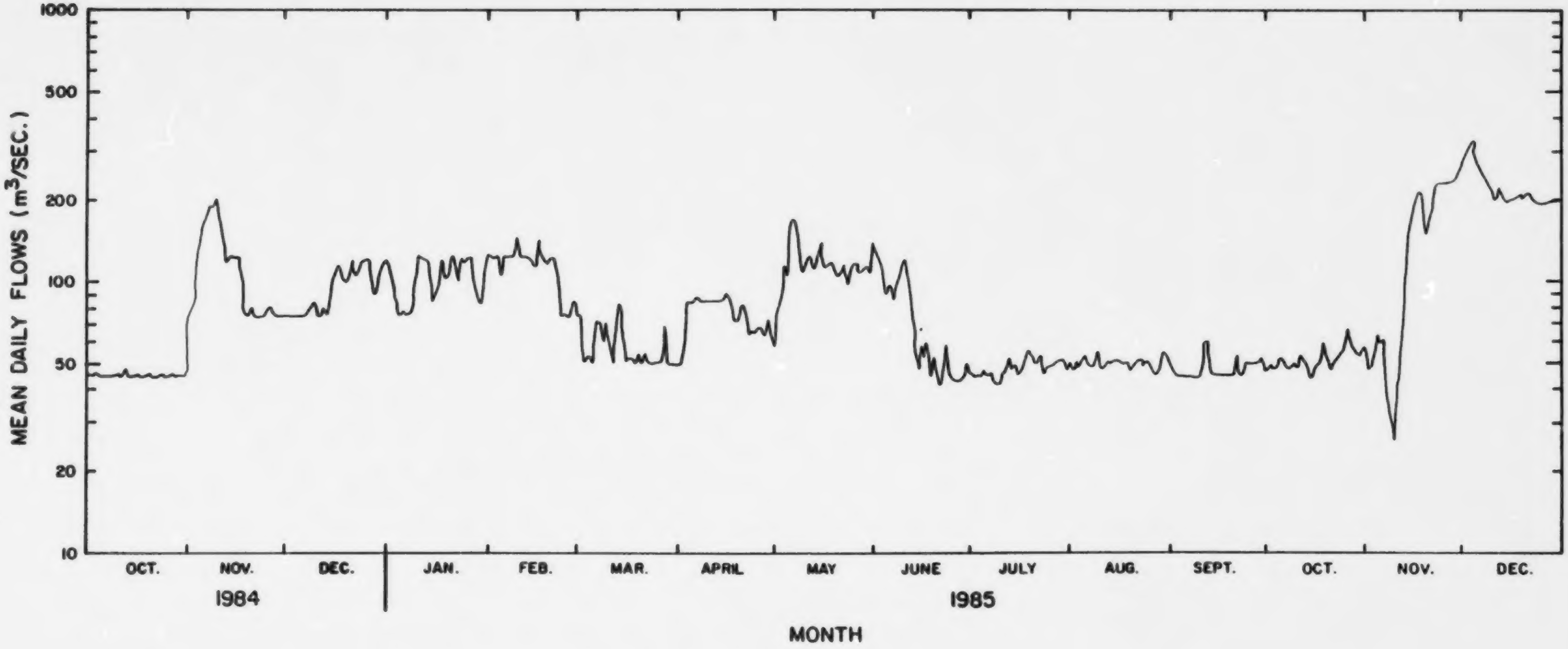


Figure 6 : DETAILED HYDROGRAPH FOR THE SOUTH SASKATCHEWAN RIVER BELOW GARDINER DAM (MEASURED AT SASKATOON), 1984-1985

3. RIVER CHEMISTRY

3.1 Assessment Methodology

3.1.1 Sampling Sites

Seven river sampling locations were established for the study (see Table 2 and Figure 1). The two upstream sites - Red Deer River near Bindloss (R1) and South Saskatchewan River at No. 41 Highway (R2) - are in Alberta just upstream of the Saskatchewan/Alberta border. These stations coincide with sites which the Water Quality Branch (WQB) of Environment Canada has monitored monthly for the PPWB since 1974. Downstream of the confluence, sites were established at Leader (R3) and Lemsford Ferry (R4). Sampling of the above four locations was designed to examine variability in loading to Lake Diefenbaker. Sites at Qu'Appelle River at Highway No. 19 (R6) and South Saskatchewan River near Outlook (R7) examined output from Lake Diefenbaker.

Beginning in October, 1984, two sites were selected for intensive sampling. These sites were the South Saskatchewan River at Lemsford Ferry and the outlet of Lake Diefenbaker at Gardiner Dam. This sampling was undertaken to address the nutrient loadings question.

3.1.2 Sampling Schedule and Field Methods

Since the intent of the study was to emphasize loadings to Lake Diefenbaker, the sampling frequency varied with

Table 2
River Sampling Sites, 1984-85

Station No.	Name
R1.	Red Deer River Near Bindloss
R2.	South Saskatchewan River at Highway 41
R3.	South Saskatchewan River near Leader
R4.	South Saskatchewan River at Lemsford Ferry*
R5.	South Saskatchewan River at Gardiner Dam*
R6.	Qu'Appelle River at Highway 19
R7.	South Saskatchewan River near Outlook

* sites associated with intensive nutrient sampling

discharge (see sampling dates in Table 3). The sampling schedule was designed to take into account major hydrologic events as well as summer and winter low flow periods. Individual storms were not considered as significant hydrologic events due to the size and complexity of the basin which tends to dampen the effects of all but the largest storm events at the sampling points selected for this study.

Water samples were collected and preservation done in essentially the same manner as employed by WQB in their routine sampling program (Environment Canada 1981). At the four upstream sites three samples were taken, one from the mid-point of each third of the channel width.

These samples were collected from an anchored boat at all sites except for the Red Deer River at Bindloss where the road bridge provides excellent access. Winter samples were collected through the ice. A sampling iron was used to collect a depth integrated sample. Bottles were rinsed with sample water and preserved and/or filtered in the field, or stored in a cooler until delivery to the laboratories, usually within a few days.

The sampling for the intensive nutrient monitoring program at Lemsford and Gardiner Dam was performed by contract personnel. This program was initiated in October, 1984 and is ongoing. Samples are collected according to WQB standard field procedures. Sampling frequency is flow weighted - varying from twice per week during high flow periods to twice per month during low flows.

3.1.3 Parameters

Table 3 also provides a list of parameters sampled at the river sites during the study, and gives some brief comments regarding the environmental significance of these parameters.

Table 3

River Monitoring Details, 1984-85

Dates	Parameters		Significance
July 10, 11; Sept. 10, 11 Oct. 23, 24; Jan. 23, 24; Apr. 10, 11; Apr. 16, 17; June 20, 21	(i)	Nutrients	
		- dissolved nitrogen (DN)	- soluble nitrogen that includes nitrates, nitrites and ammonia; these compounds are readily available for biological uptake by aquatic organisms including algae and plants.
		- particulate nitrogen (PN)	- nitrogen associated with any particulate or suspended matter in the water column - usually micro-organisms, organic detritus, etc.; nitrogen can be released in bioavailable forms from PN through leaching or microbial decay.
		- total nitrogen (TN)	- calculated parameter; sum of dissolved and particulate nitrogen
		- dissolved phosphorus (DP)	- soluble phosphorus that is largely biologically available for uptake by aquatic plants and algae
		- particulate phosphorus (PP)	- phosphorus associated with suspended matter in the water column - may represent up to 95% of the total phosphorus present
		- total phosphorus (TP)	- total organic plus inorganic phosphorus present in the system; phosphorus is an essential plant nutrient and may be a limiting factor for plant growth
		- dissolved organic carbon (DOC)	- soluble carbon; decomposition of dissolved organic carbon removes oxygen from the water

Table 3 (continued)

River Monitoring Details, 1984-85

Dates	Parameters	Significance
	- particulate organic carbon (POC)	- associated with particulate matter in the water; sources include runoff from forested and agricultural lands, detrital input such as leaves, and municipal waste discharges
	- total organic carbon (TOC)	- calculated parameter; sum of all carbon in the system
	(ii) Major Ions and Physical Parameters	
	- calcium	- one of the most abundant cations in surface and ground waters; calcium along with magnesium is primarily responsible for the hardness of water
	- magnesium	- as above
	- potassium	- an essential element for plant and animal nutrition
	- sodium	- principle alkali metal; sodium can adversely affect soil structure and create alkali soils, which impair agricultural uses
	- chloride	- a measure of the inorganic chloride ion
	- sulphate	- is the stable, highly oxidized form of sulphur
	- total dissolved solids (TDS)	- is an index of the amount of dissolved substances in the water
	- pH	- measure of the hydrogen ion concentration; indicates the balance between the acids and bases in water

Table 3 (continued)

River Monitoring Details, 1984-85

Dates	Parameters	Significance
	- conductivity	- measure of a water's capacity to convey an electric current; is related to the total concentration of the ionized substances in water
	- total suspended solids (TSS)	- non-filterable residue; particulate matter including suspended sediment can reduce water clarity
	- total hardness	- calculated parameter; determined by the sum of calcium and magnesium
	- total alkalinity	- calculated parameter; measure of a water's capacity to neutralize an acid; indicates the presence of carbonates, bicarbonates and hydroxides

3.2 Results and Discussion

3.2.1 Nutrients

For the purposes of this report the results of the intensive nutrient monitoring study on the South Saskatchewan River, initiated in the fall of 1984, are presented. The annual cycles are well illustrated because of the increased sampling frequency. First, the data for Lemsford will be considered followed by the data for the Gardiner site, and finally some direct comparisons of the two sites. The Lemsford site will be considered as the input to Lake Diefenbaker and the Gardiner site will be considered the output.

Quality Assurance

Field methods for the intensive nutrient monitoring program followed approved methods such as those recommended in the Environment Canada manual entitled Sampling for Water Quality (1983). A Quality Assurance (QA) program was implemented to ensure a specified degree of confidence in the data collected for the survey.

As previously noted, contractors were engaged to conduct sampling at Lemsford and Gardiner Dam. The contractor's sampling methods were essentially identical to those of the Water Quality Branch. The main difference was that the contractor's samples were not filtered or preserved until they arrived at the Saskatoon laboratory. WQB samples were filtered and preserved in the field immediately following collection. Since two sampling methods were used, duplicate sampling to compare the two methods was done (Table 4).

The differences that occurred between the WQB and the contractor's methods were minimal and therefore the data can be confidently compared.

Table 4

A Comparison of Replicate Samples for Lemsford

		Parameter				
Sampling Date	Code	TP	DP	DN	PN	DOC
Oct. 24/84	a	0.046	.004	0.16	0.40	2.3
	a	0.044	L.003	0.17	0.31	2.4
	c	0.049	L.003	0.17	0.14	2.4
	a	0.044	.003	0.15	0.38	2.3
	c	0.044	L.003	0.17	0.17	2.4
	c	0.044	L.003	0.17	0.17	2.4
	c	0.046	L.003	0.17	0.14	2.3
Oct. 25/84	b	0.046		0.19	0.17	2.5
Jan. 24/85	a	.032	.008	1.8	0.06	1.4
	a	.034	.010	1.8	0.05	1.5
	a	.037	.010	1.8	0.07	1.4
	b	.030	.021	1.8	0.05	1.7
	c	.031	.015	1.8	0.12	1.4
	c	.031	.018	1.7	0.04	1.4
	c	.032	.015	1.8	0.07	1.4
Apr. 11/85	a	.550	.024	1.2	1.5	5.2
	a	.550	.031	1.4	1.8	5.4
	a	.550	.026	1.2	1.2	5.8
	b	.600	.040	1.0	1.7	4.0
June 19/85	b	.083	.005	0.15	0.16	2.1
June 21/85	a	.096	.004	0.13	0.31	2.3
	a	.095	.004	0.12	0.30	2.4
	a	.096	.003	0.12	0.29	2.4

a = WQB regular sample (Field Filtered)
b = contract sample (Lab Filtered)
c = contract sample method collected by WQB (Lab Filtered)

Nitrogen

In Saskatchewan, surface water quality objectives have been established for total nitrogen at 1.0 milligrams per litre (mg/L) (Saskatchewan Environment, 1983). It is recognized, however, that many surface waters in Saskatchewan have naturally high levels of nutrients.

In 1985, total nitrogen (TN) concentration at Lemsford, as shown in Figure 7, peaked in the spring followed by another increase in association with the mountain snowmelt followed by low summer concentrations. The late fall and winter TN concentrations gradually rose to a mid-winter high followed by a slight decline in advance of the snowmelt event. Concentrations at Lemsford exceeded the water quality objective of 1.0 mg/L throughout the winter, into the spring and occasionally during the fall as well.

The distribution of TN between dissolved nitrogen (DN) and particulate nitrogen (PN) is variable throughout the year. DN is the dominant form throughout the fall and winter season. During the high flow events, PN becomes dominant although DN is still important. During the summer period, the nitrogen is essentially equally distributed between the dissolved and particulate forms.

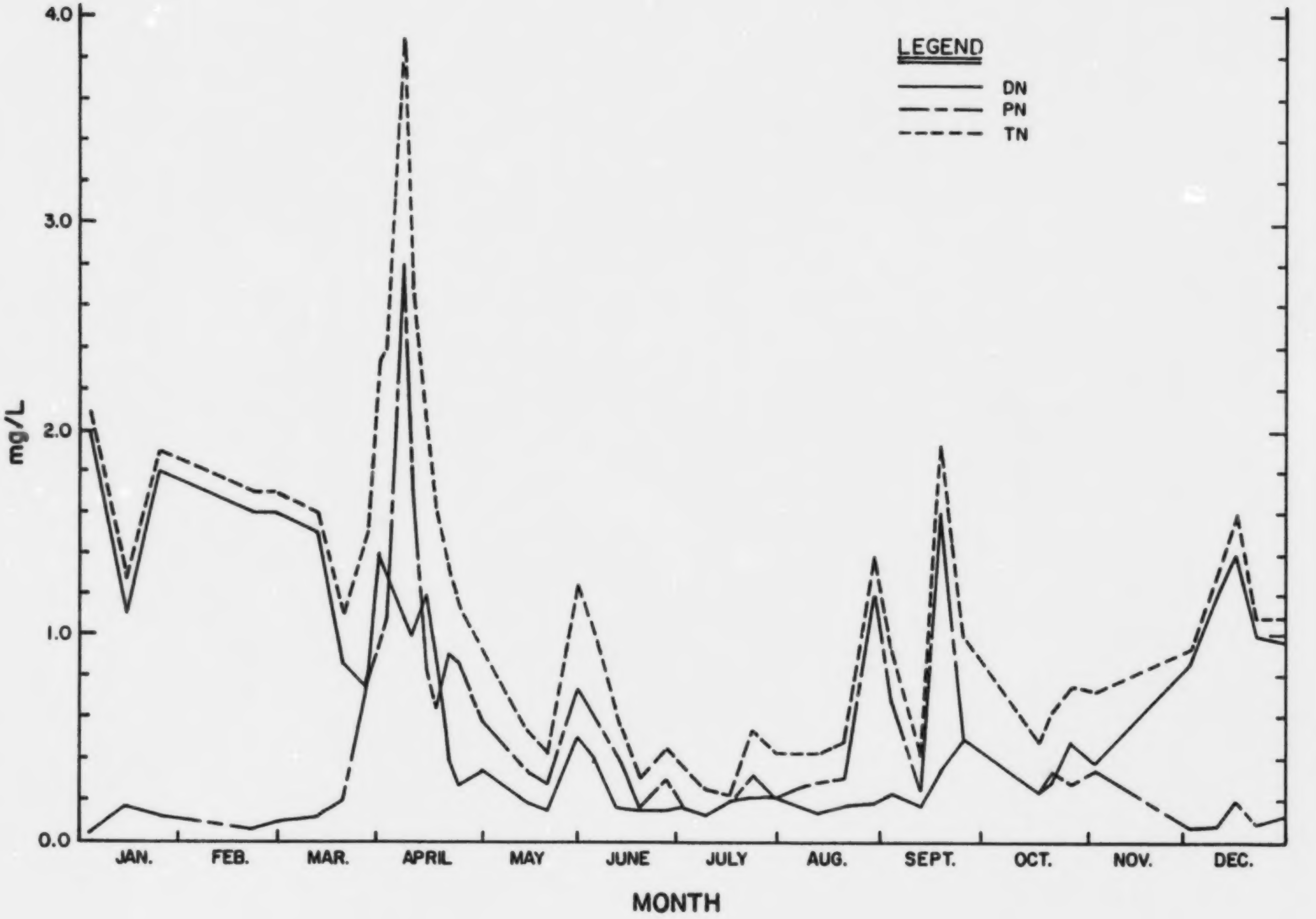


Figure 7 : NITROGEN DATA FOR LEMSFORD SITE , 1985

As shown in Figure 8, DN is the dominant nitrogen form at the Gardiner site throughout the year. PN is uniformly low at less than 0.08 mg/L. This reflects the settling of particulate material along the length of Lake Diefenbaker.

TN concentrations remained relatively stable throughout the year, ranging from 0.19 mg/L to 0.34 mg/L. TN concentrations in 1985 were well below the provincial water quality objective (1.0 mg/L).

DN concentrations for the two sites are compared in Figure 9. DN concentrations at Lemsford varied greatly throughout the year. Lowest concentrations (approximately 0.2 mg/L) were measured from April to October. During winter, DN concentrations exceeded 1.0 mg/L. DN at the Gardiner site was almost constant throughout the year at about 0.2 mg/L.

Phosphorus

The current provincial surface water quality objective pertains to total phosphorus (0.05 mg/L), but, as is the case with total nitrogen, the objective may not be achievable in some naturally nutrient-enriched waters common to the prairie environment.

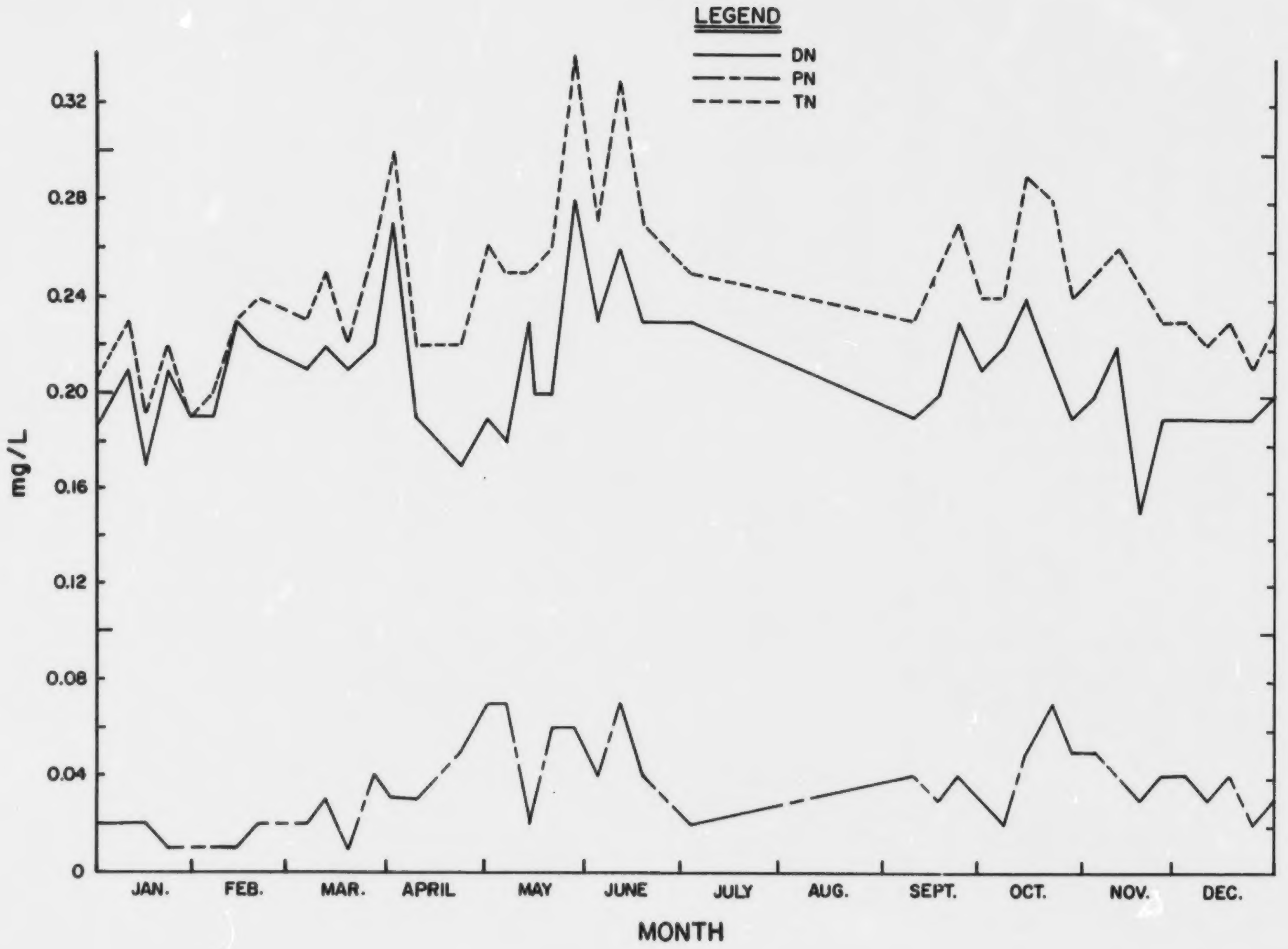


Figure 8 : NITROGEN DATA FOR GARDINER SITE , 1985

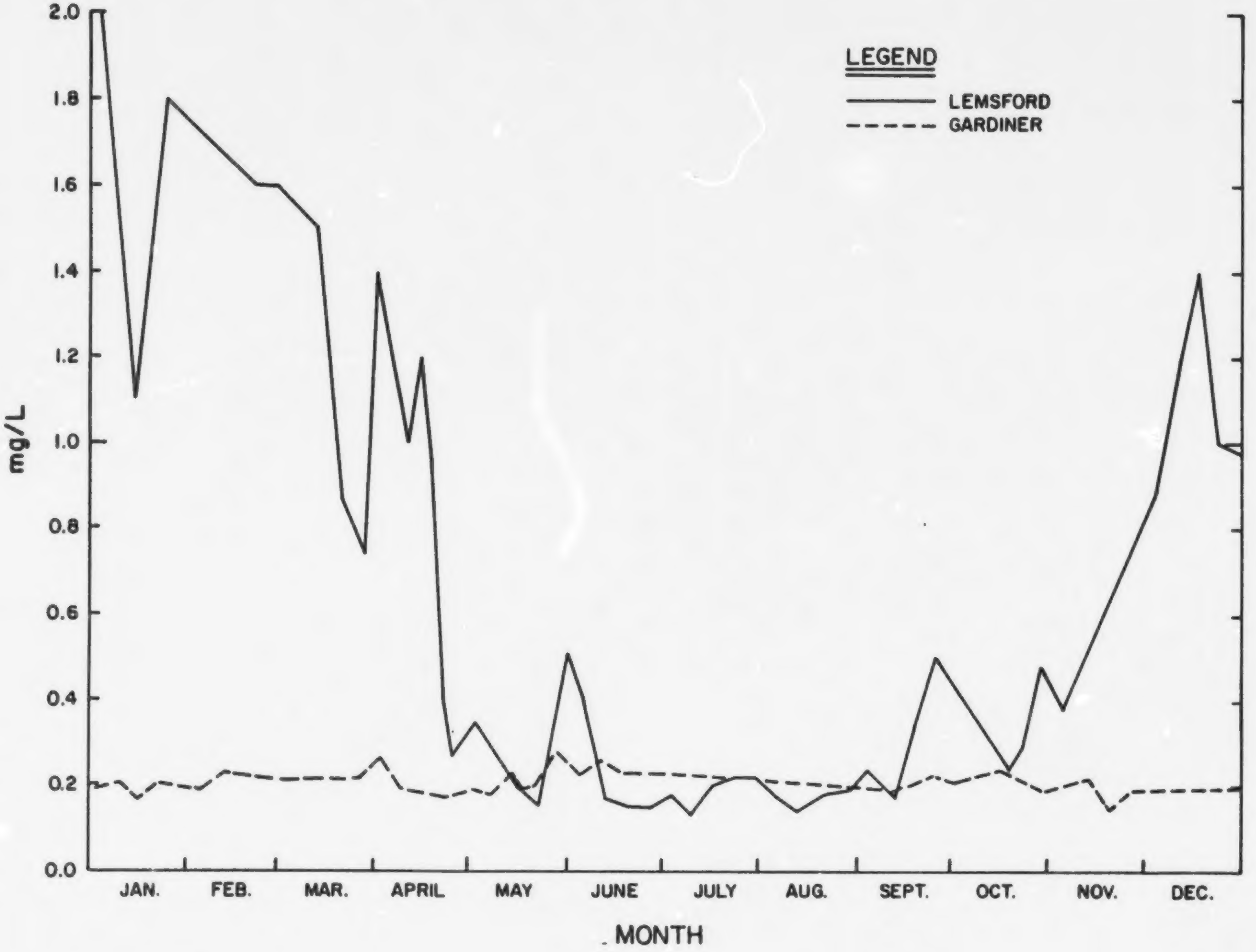


Figure 9 : COMPARISON OF DN FOR GARDINER AND LEMSFORD SITES , 1985

Although 1985 was a low flow year, an annual cycle of phosphorus concentrations was evident at Lemsford (Figure 10). Maximum TP concentrations occurred in late March and early April in association with prairie snowmelt. TP concentrations declined rapidly from the peak, in association with decreasing flows, and then rose again in early June in response to increased flow resulting from mountain runoff. An increase in TP during the fall was primarily a result of increased flow from the Red Deer River.

Phosphorus at Lemsford was predominantly of the particulate form (PP). The pattern changed only slightly throughout the year with marginal increases in DP occurring only in association with the prairie snowmelt event. The association of phosphorus with fine-grained sediments is well established. The correspondence between TP and total suspended solids are evident in a comparison of Figures 10 and 11.

TP results at Lemsford exceeded the Saskatchewan total phosphorus objective of 0.05 mg/L on numerous occasions during the study period.

The TP data for the South Saskatchewan River at Gardiner Dam are graphed in Figure 12. In general, TP concentrations were low, less than 0.014 mg/L, although

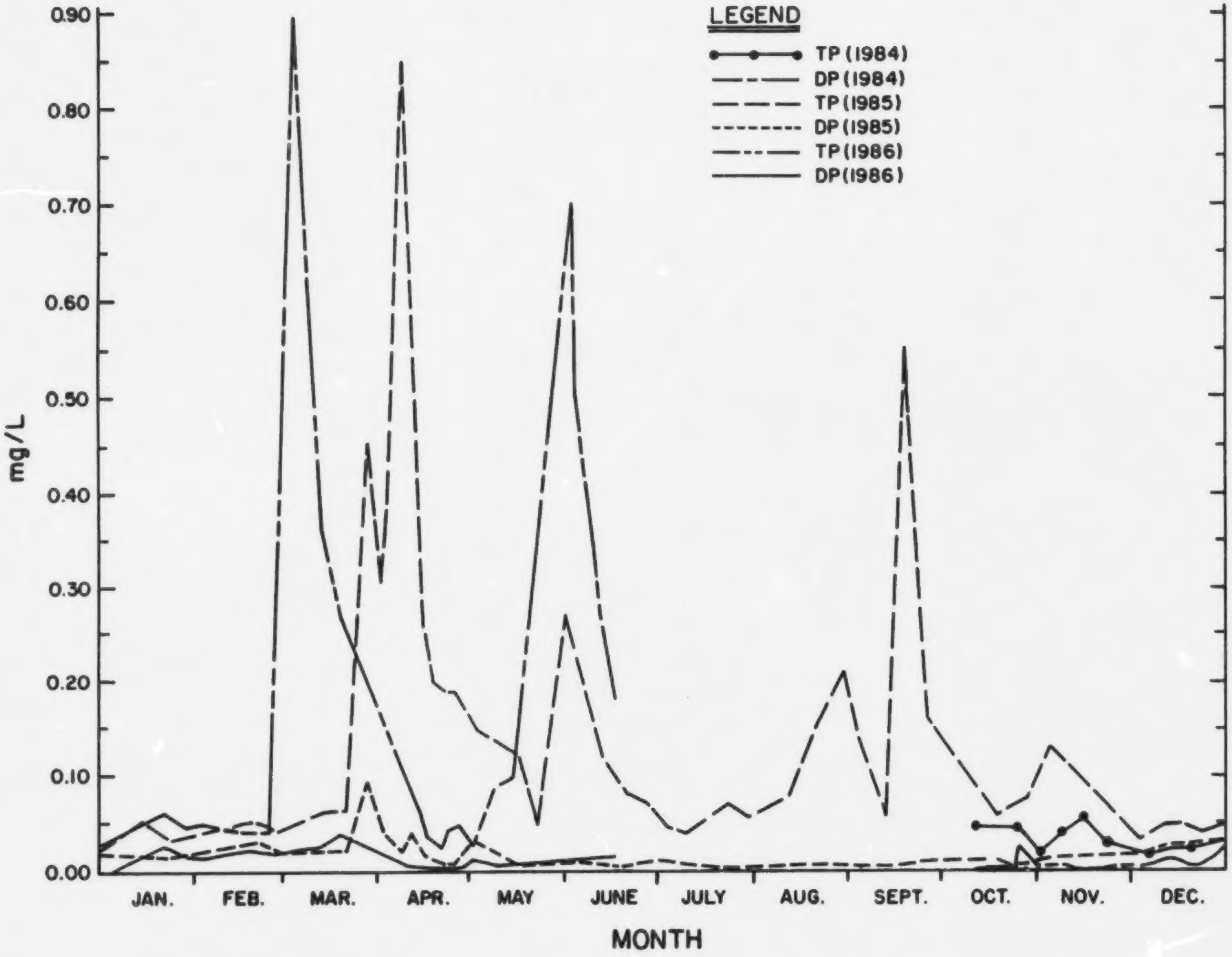


Figure 10 : PHOSPHORUS DATA FOR LEMSFORD SITE

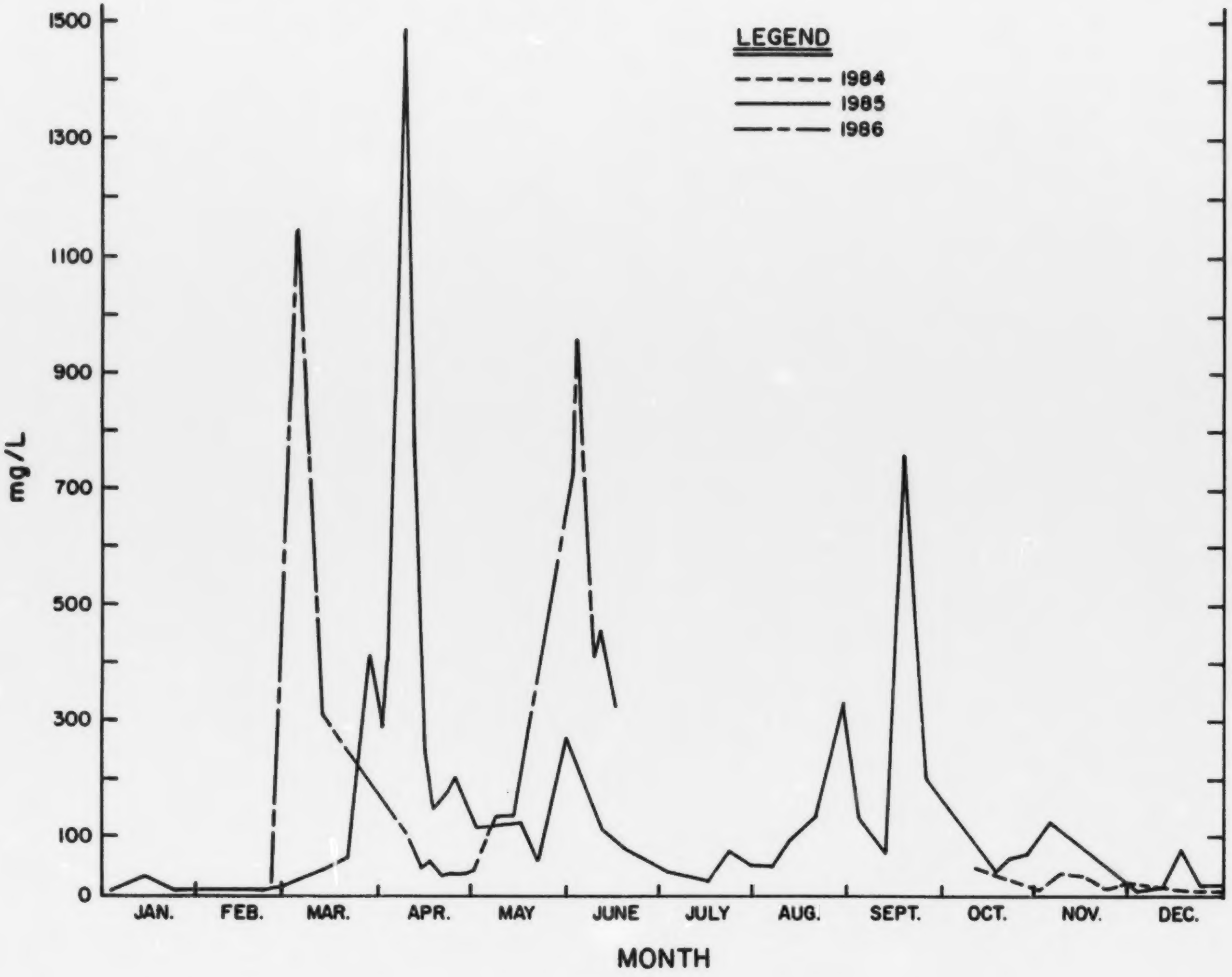


Figure 11: TSS FOR LEMSFORD SITE

higher concentrations did occur in late May and early June in 1985. No exceedences of the provincial TP objective were recorded at this site during the study period.

The 1985 data for DP, PP and TP at Gardiner Dam are compared in Figure 13. In contrast to the Lemsford site, DP was the dominant form throughout much of the year at Gardiner. PP made up a larger proportion of TP in the period from mid-April to mid-June, coincident with the higher TP concentrations. Neither turbidity nor TSS increased during this same time period. A possible explanation is increased organic matter in association with or following an algal bloom. Although the trend is not obvious, particulate organic carbon (POC) did increase by about a factor of two at this same time. Whether this is sufficient to account for an order of magnitude increase in PP is unknown. Continued monitoring of the outflow chemistry is necessary to understand the nutrient cycles more fully.

A comparison of TP concentrations during 1985 at the Lemsford and Gardiner Dam sites is presented in Figure 14. It is noteworthy that TP at the Gardiner site was approximately an order of magnitude less than the TP concentration at Lemsford, and that the variability of concentration at Gardiner Dam is greatly dampened.

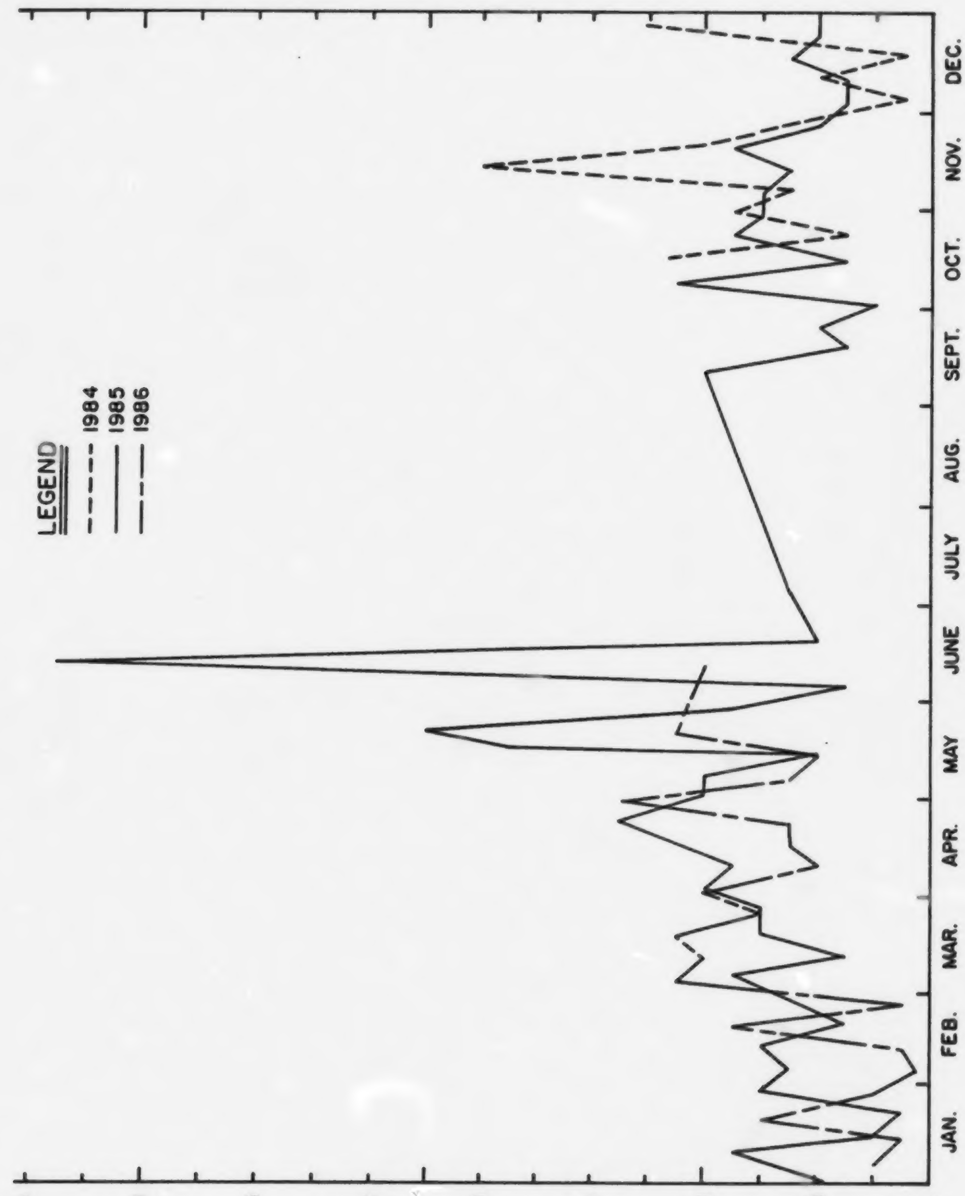


Figure 12 : TP DATA FOR GARDINER SITE

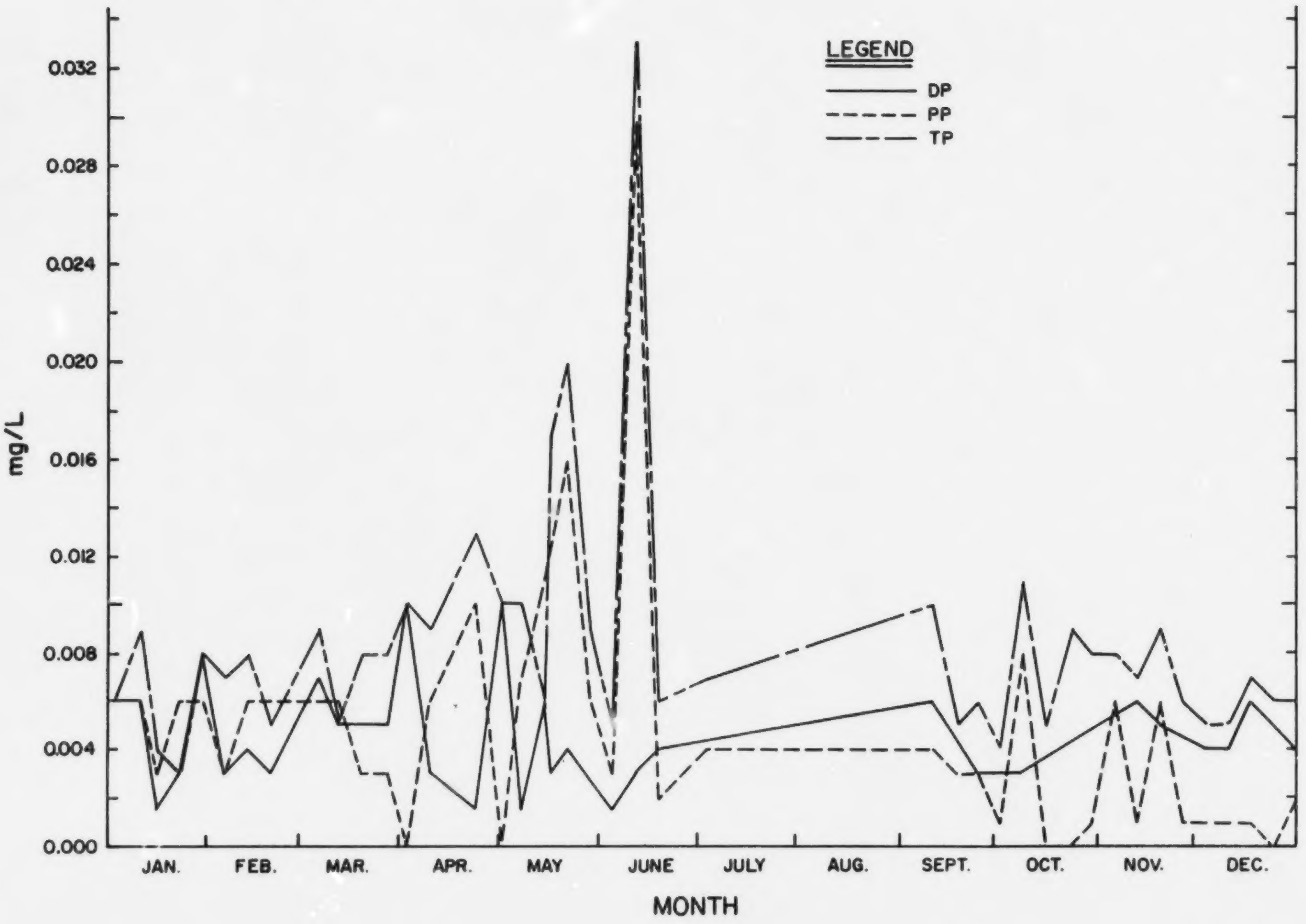


Figure 13 : COMPARISON OF DP , PP AND TP FOR GARDINER SITE , 1985

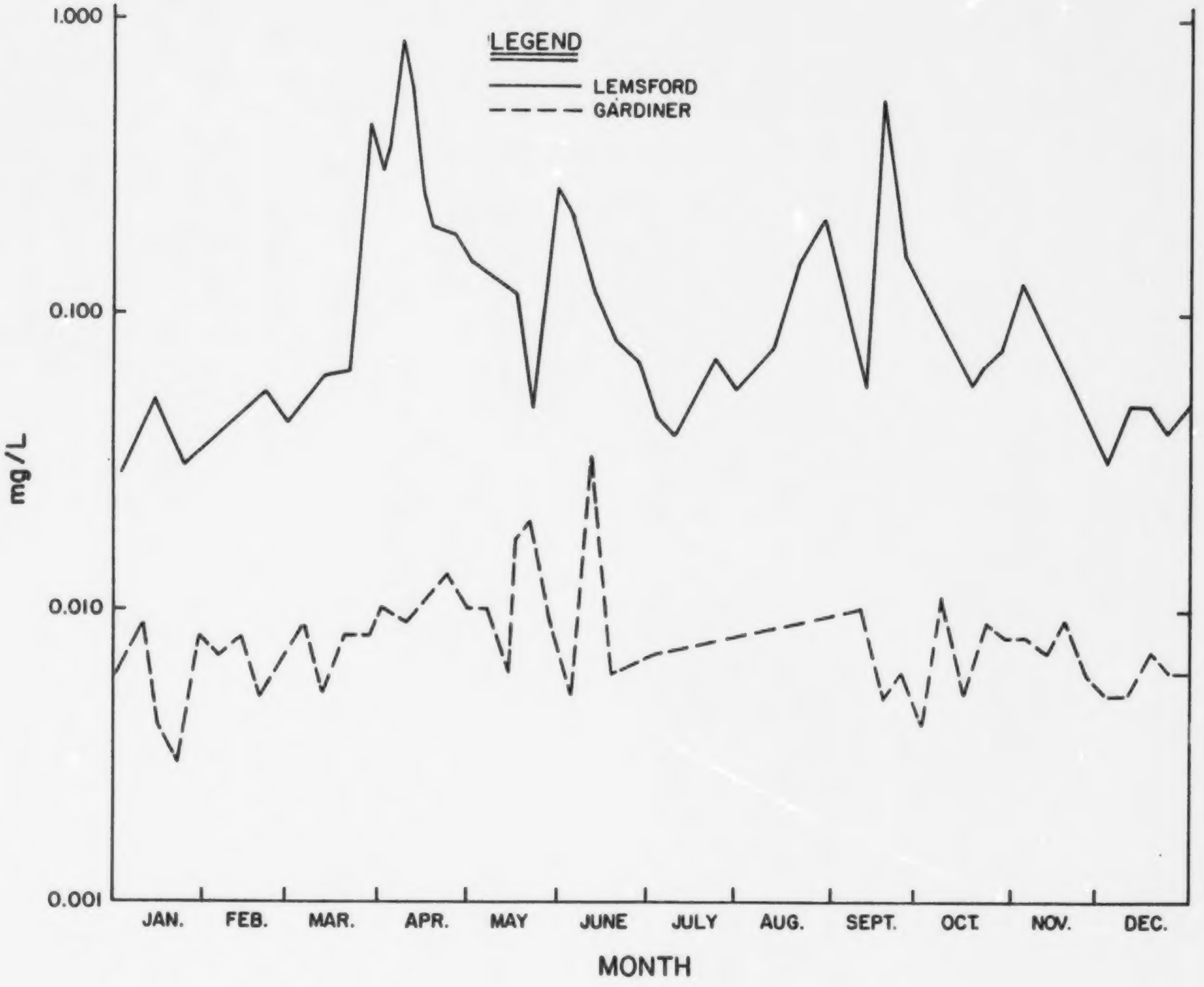


Figure 14 : COMPARISON OF TP FOR LEMSFORD AND GARDINER SITES , 1985

Carbon

Organic carbon data for the South Saskatchewan River at Lemsford are shown for 1985 in Figure 15. The overall pattern for total organic carbon (TOC) parallels that of TP with maximums occurring in association with high flow events and minimums during the winter season. DOC is dominant throughout the year except during the high flow events when particulate organic carbon (POC) dominates.

DOC and POC data for Gardiner Dam for the period of record are graphed in Figure 16. DOC is almost always an order of magnitude greater than POC. There is little variability in the carbon data, and seasonal cycles are not readily evident.

3.2.2 Phosphorus Loading to Lake Diefenbaker

(a) Monthly Monitoring Data

Estimates of phosphorus loading to Lake Diefenbaker are made possible by summing the above confluence loadings of the mainstem South Saskatchewan (at Highway 41) and Red Deer (near Bindloss) Rivers. As mentioned earlier, these sites have been monitored monthly by Environment Canada since 1974. The calculation method used is as follows:

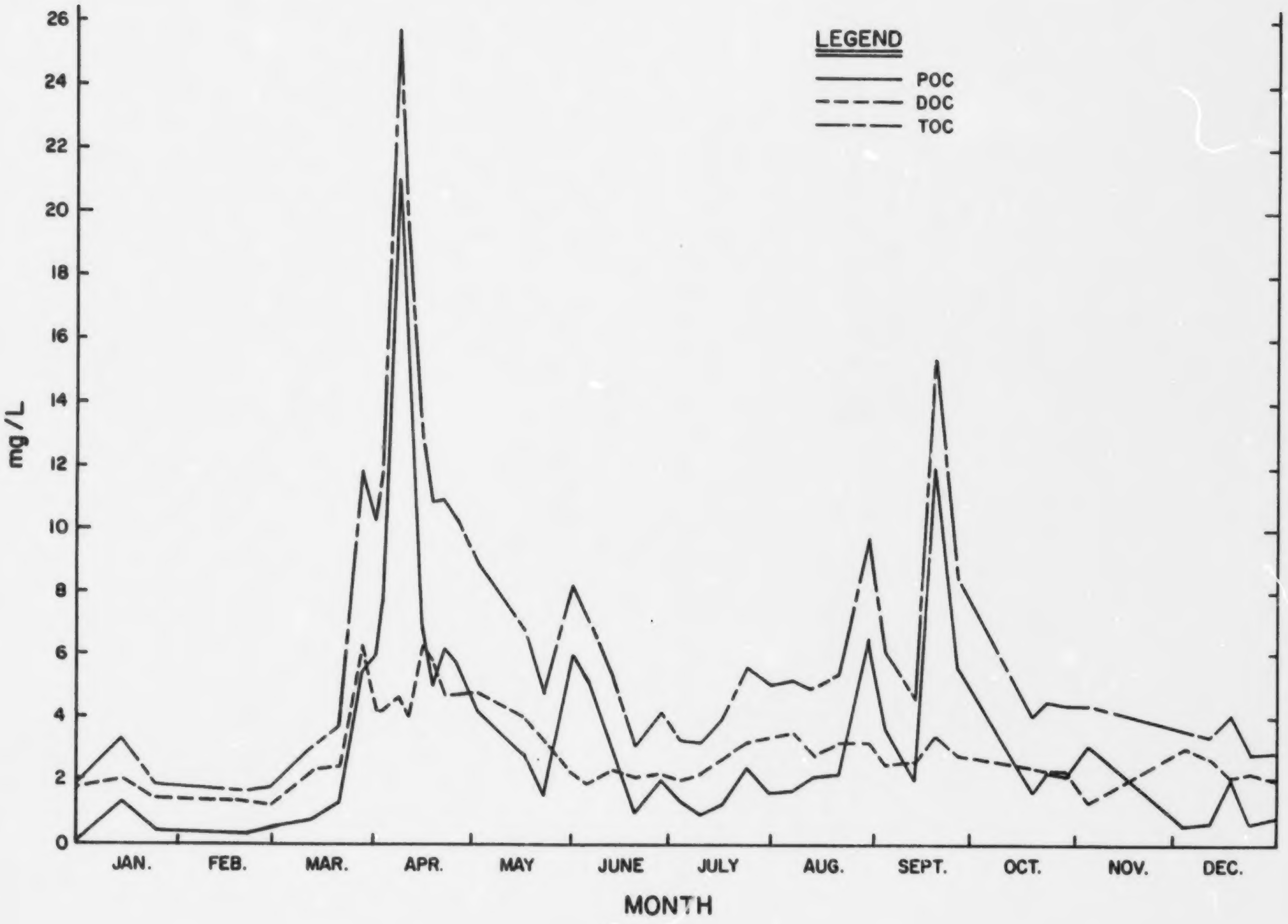


Figure 15 : TOC , POC AND DOC DATA FOR LEMSFORD , 1985

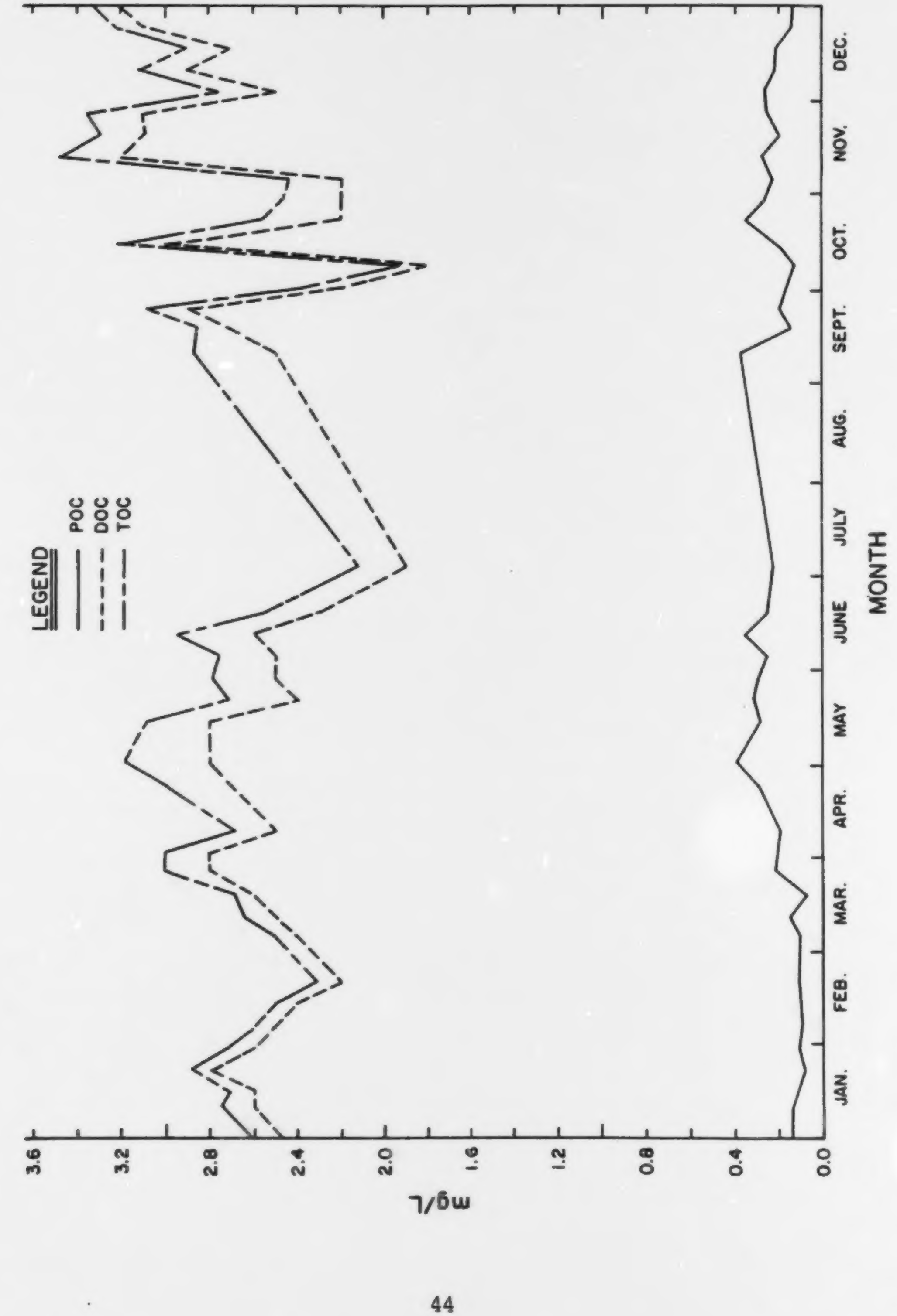


Figure 16 : GARDINER SITE CARBON DATA , 1985

$$L \doteq \sum_{i=1}^{n} Ci * Qi * Wi * .0864 * QF$$

where L = annual phosphorus load (tonnes as P)

i = observations 1, 2, 3 ...

n = number of observations of concentration during year (usually 12)

Ci = instantaneous phosphorus concentration (mg/L)

Qi = mean daily discharge on Day i (m^3/sec)

Wi = number of days for which loading rate is assumed to be in effect

QF = measured annual discharge/ $\sum_{i=1}^{n} Qi * Wi * 86.4$ (corrects for overestimates or underestimates of annual discharge in the function)

The calculation assumes that the phosphorus loading rate present on day i is constant during the period half way back to day i-1 and half way forward to day i+1. Thus, loading calculations are most accurate as n, or number of observations, increases. As well, increasing n reduces the effect of analytical or sampling error in individual measurements of Ci (in other words the Wi associated with the inaccurate Ci would be small).

The importance of maximizing n increases with water quality parameters that display annual concentration cycles, especially where concentration tends to maximize with the hydrograph. As noted in the previous chapter, total phosphorus (TP) concentration tends to peak during high discharge periods, due to the direct relationship between TP and suspended sediment. Therefore, estimates of TP loading based on relatively low frequency sampling (n=12) are susceptible to error. The chance of sizeable error is greatly increased during years with high discharge (and high corresponding sediment transport).

Dissolved phosphorus (DP) concentrations were shown to be less variable, with a tendency to maximum concentration occurring during the low flow winter period. Thus, the error in the DP annual loading calculations associated with monthly sampling would be expected to be relatively small, even during high flow years.

It should be noted that the estimates of loading into Lake Diefenbaker, based upon data from upstream tributary sites, assumes that there are no losses or gains to the nutrient load between the sampling sites and the lake. Sedimentation, resuspension, external inputs during major storm events, and internal biogeochemical interactions could all affect this assumption. The validity of this assumption will be discussed in the next section, where phosphorus loading calculations from the intensive nutrient work at Lemsford in 1985 are compared to the tributary calculations.

The estimates of phosphorus loading into Lake Diefenbaker (1975-1985) based on the monthly monitoring record are presented in Table 5 and Figure 17.

TP loading into Lake Diefenbaker was variable from year to year (Figure 17), ranging nearly an order of magnitude from 247 tonnes (1984) to 2077 tonnes (1980). The mean annual TP load into Lake Diefenbaker (1975-1985) was 1229 tonnes. It can be seen that the lowest TP loading occurred in the two years with lowest total discharge (1977 and 1984). The maximum TP loading year (1980) had the second highest total discharge during the period.

Of the two tributary sources, the main stem South Saskatchewan River (SSR) tended to contribute slightly more TP load (mean annual 711.5 tonnes) than the Red Deer River (RDR) (mean annual 517.5 tonnes), though the contribution from the RDR exceeded the SSR in some years (1977, 1980, 1983).

Table 5

Estimates of Annual Phosphorus Loading into Lake Diefenbaker Calculated from Monthly Monitoring Data (1975-1985)

Year	Total Q dam^3 (1)	TP Load tonnes (2)	DP Load tonnes (2)	Total Q function dam^3 (3)	QF (4)	TP Load correct. tonnes (5)	DP Load correct. tonnes (5)
			South Saskatchewan River at Highway 41				
1975	4791000	1710.3	—	6922000	0.69	1183.5	—
1976	3648000	2793.8	—	6061000	0.60	1681.9	—
1977	1452000	120.6	—	2235000	0.65	78.4	—
1978	4160000	1496.3	134.9	6739000	0.62	923.2	83.2
1979	3960000	541.4	131.9	3990000	0.99	537.1	130.8
1980	4610000	762.2	165.5	4278000	1.08	821.7	178.4
1981	6920000	677.8	109.4	5416000	1.28	866.2	139.8
1982	4140000	760.0	145.7	4227000	0.98	744.0	142.6
1983	2940000	304.3	50.6	3139000	0.94	285.1	47.4
1984	2170000	132.8	32.5	2177000	1.00	132.4	32.4
1985	3010000	607.9	51.1	3197000	0.94	572.6	48.1
Mean	3800000					711.5	100.3
			Red Deer River near Bindloss				
1975	805000	384.4	—	1143000	0.70	270.6	—
1976	819000	317.6	—	1193000	0.69	218.2	—
1977	747000	366.5	—	1496000	0.50	182.9	—
1978	1127000	695.6	38.8	1642000	0.69	477.2	26.6
1979	990000	154.3	20.1	921000	1.08	165.9	21.6
1980	1650000	1584.5	25.8	2083000	0.79	1254.9	20.4
1981	2330000	588.9	20.0	2055000	1.13	667.8	22.7
1982	1970000	886.5	43.2	2394000	0.82	729.6	35.6
1983	1240000	1527.8	22.1	1419000	0.87	1335.3	19.3
1984	925000	116.3	8.2	935000	0.99	115.0	8.1
1985	1310000	275.2	14.4	1309000	1.00	275.5	14.4
Mean	12650000					517.5	21.1
			Combined Loads (into Lake Diefenbaker)				
1975	5596000					1454.	—
1976	4467000					1900.	—
1977	2199000					261.	—
1978	5287000					1400.	110.
1979	4950000					703.	152.
1980	6260000					2077.	199.
1981	9250000					1534.	162.
1982	6110000					1474.	178.
1983	4180000					1620.	67.
1984	3095000					247.	40.
1985	4320000					848.	62.
Mean	5064000					1229.	121.

(1) Data from Water Survey of Canada (1975-1985). Annual discharges listed for combined loads are summed discharges of SSR + RDR.

(2) Calculated from: $\sum_{i=1}^{n}$ Ci * Qi * Wi * .0864 (all loads as P).

(3) $\sum_{i=1}^{n}$ Qi * Wi*86.4

(4) Total Q (measured) / $\sum_{i=1}^{n}$ Qi * Wi*86.4 (this factor corrects for overestimates or underestimates of annual discharge in the function)

(5) Calculated from: $\sum_{i=1}^{n}$ Ci * Qi * Wi* .0864 *QF

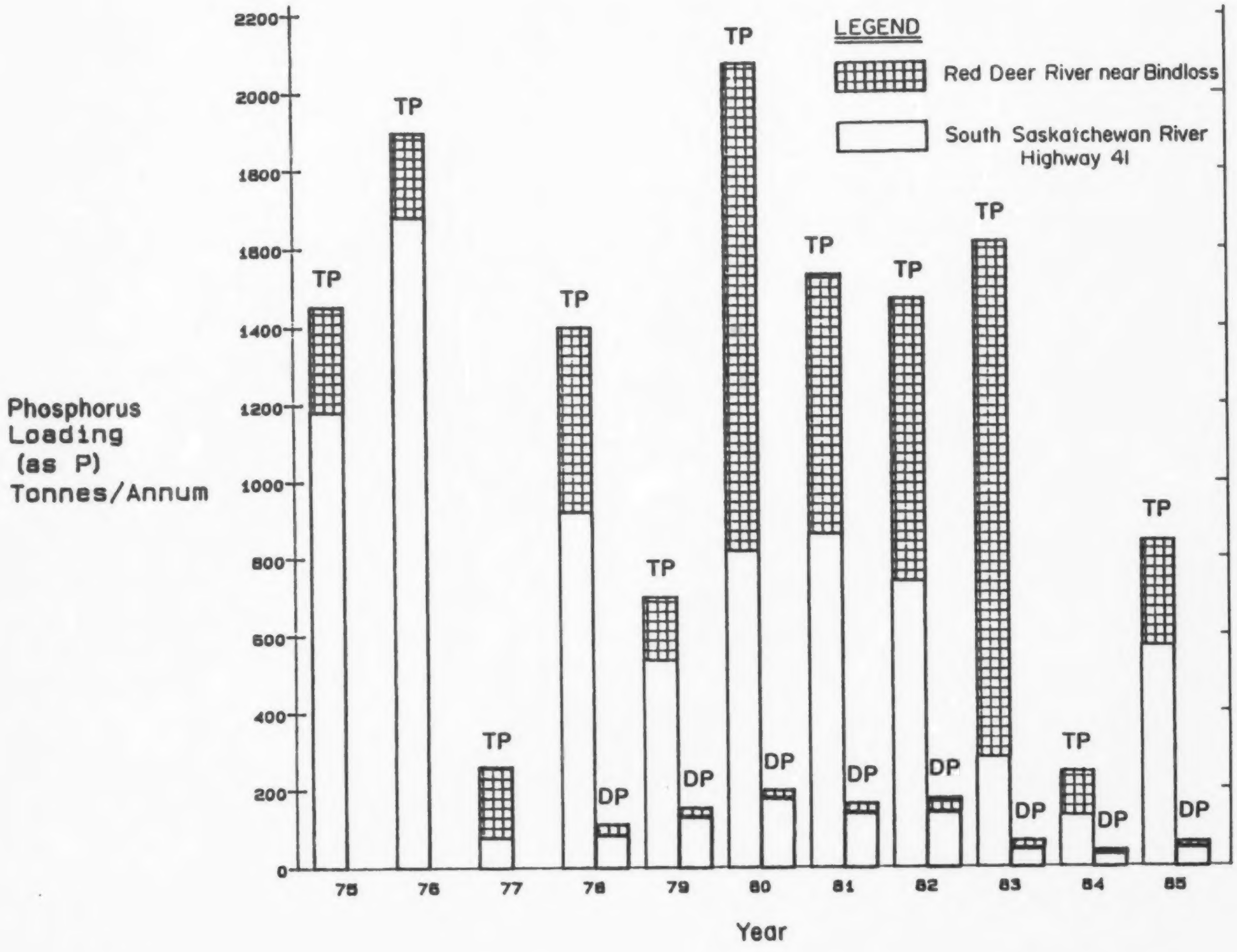


Figure 17 : ANNUAL PHOSPHORUS LOADING INTO LAKE DIEFENBAKER , 1975 - 1985

During these years the ratio of SSR discharge: RDR discharge varied between 2 and 3, reflecting substantially higher TP concentrations at the RDR site.

DP loading into Lake Diefenbaker varied less from year to year than TP, ranging from 40 tonnes (1984) to 199 tonnes (1980), and with a 1978-1985 mean of 121 tonnes (analysis of DP was not initiated until 1978).

The SSR contribution of DP load (mean annual 100.3 tonnes) exceeded that of the RDR (mean annual 21.1 tonnes) throughout the period. DP/TP percentages in the SSR ranged from 8%-24% (mean 17%). DP/TP percentages were much lower in the RDR, with a range from 1%-13% (mean 5%). The mean annual DP/TP percentage entering Lake Diefenbaker was found to be 11% (range from 4%-22%).

The majority of phosphorus species making up the DP fraction are biologically available. DP is composed largely of dissolved organic phosphates (analytically known as dissolved reactive P), which are directly bioavailable. Other DP forms include condensed phosphates and dissolved organic phosphorus, which can generally be converted to bioavailable forms through hydrolysis or biological mineralization. (The commonly analyzed form known as ortho-phosphorus includes dissolved reactive P plus a portion of the dissolved condensed phosphates).

The DP/TP percentages show that approximately 89% of the TP load entering Lake Diefenbaker annually is of the particulate phosphorus (PP) fraction. A large percentage of PP is non-available biologically, made up largely of apatite-P, a calcium bound erosion product. Other PP forms include non-apatite inorganic phosphorus, which is partially available through a number of mechanisms; organic P, which can be made available through biological mineralization; and condensed P, a small though hydrolizable fraction. As yet the suspended sediments of the South Saskatchewan river in Saskatchewan have not been assessed for biological availability.

The percentage of total phosphorus that is bioavailable can differ substantially between streams depending upon a number of geological, chemical, and biological factors. The determination of biologically available phosphorus in the suspended sediments of the SSR and RDR should certainly be an area of future study.

Figure 18 shows the monthly mean TP loads (1975-1985) delivered to Lake Diefenbaker from the SSR and RDR. The months April to July dominate, with 83% of the annual loading occurring during that time (Table 6). This reflects the direct relationship between TP and suspended sediment, which is at highest concentration during the spring and summer hydrologic events. It is interesting to note that the SSR tends to be the major contributor during May and June, while the RDR dominates in April and July. TP loading is typically very low during the October to February period, accounting for only 4% of the annual load. RDR loading of TP during those five months is negligible. The ratio of highest loading month (June, 299 tonnes TP) to lowest loading month (December, 5.4 tonnes TP) is 55:1.

Table 6

Monthly Mean Phosphorus Loading into
Lake Diefenbaker (1975-1985)
(Combined Loads of South Saskatchewan River at
Highway 41 and Red Deer River near Bindloss)

	Total Phosphorus			Dissolved Phosphorus			Part. Phosphorus	
Month	Mean Load 1975-1985 tonne/mo.	std dev	month/year	Mean Load 1975-1985 tonne/mo.	std dev	month/year	Mean Load 1975-1985 tonne/mo.	month/year
January	14.8	11	.01	10.5	8	.09	4.3	.00
February	15.9	7	.01	11.0	7	.09	4.9	.00
March	44.1	41	.04	23.0	21	.19	21.1	.02
April	194.2	243	.16	21.4	18	.18	172.8	.16
May	278.5	435	.23	7.0	5	.06	271.5	.25
June	299.0	298	.24	24.6	23	.20	274.4	.25
July	251.9	377	.20	8.2	7	.07	243.7	.22
August	46.9	73	.04	2.6	2	.02	44.3	.04
September	58.2	97	.05	2.1	2	.02	56.1	.05
October	12.6	8	.01	2.2	2	.02	10.4	.01
November	7.5	6	.01	3.6	4	.03	3.9	.00
December	5.4	4	.00	5.2	3	.03	0.2	.00
Annual	1229.			121.			1108.	

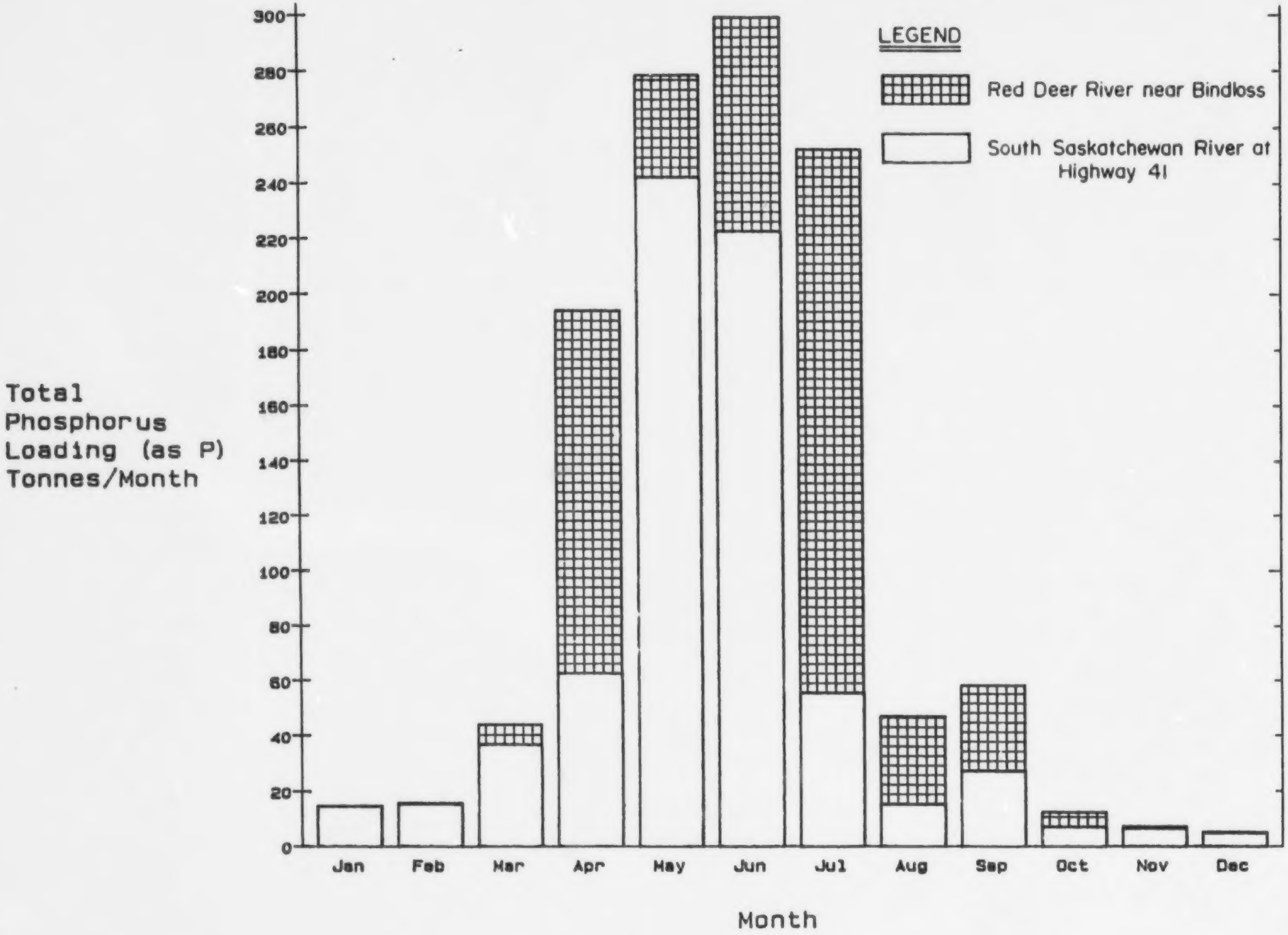


Figure 18 : MONTHLY MEAN TOTAL PHOSPHORUS LOADING INTO LAKE DIEFENBAKER, 1975 - 1985

The annual cycle of DP loading is shown in Figure 19. The period January to July accounts for 88% of DP loading to Lake Diefenbaker. Composite DP loading is dominated by the SSR throughout the year. The ratio of highest loading month (June, 24.5 tonnes DP) to lowest month (September, 2.1 tonnes DP) is 12:1.

These findings have significance with regard to the design of phosphorus monitoring strategies at the tributary sites for the calculation of loading into Lake Diefenbaker. In general, accurate TP loading calculations require reliable coverage of the April-July period, especially during high discharge years. This would be best accomplished by increasing the frequency of sampling during this period to weekly or biweekly at both SSR and RDR. Should resource considerations make increased frequency impractical, replication of the monthly samples should be considered to lend increased confidence to the analytical results. Monthly TP sampling for the remainder of the year is likely adequate. In fact, frequency of TP sampling could be reduced to bimonthly during the October-February period with little loss in accuracy.

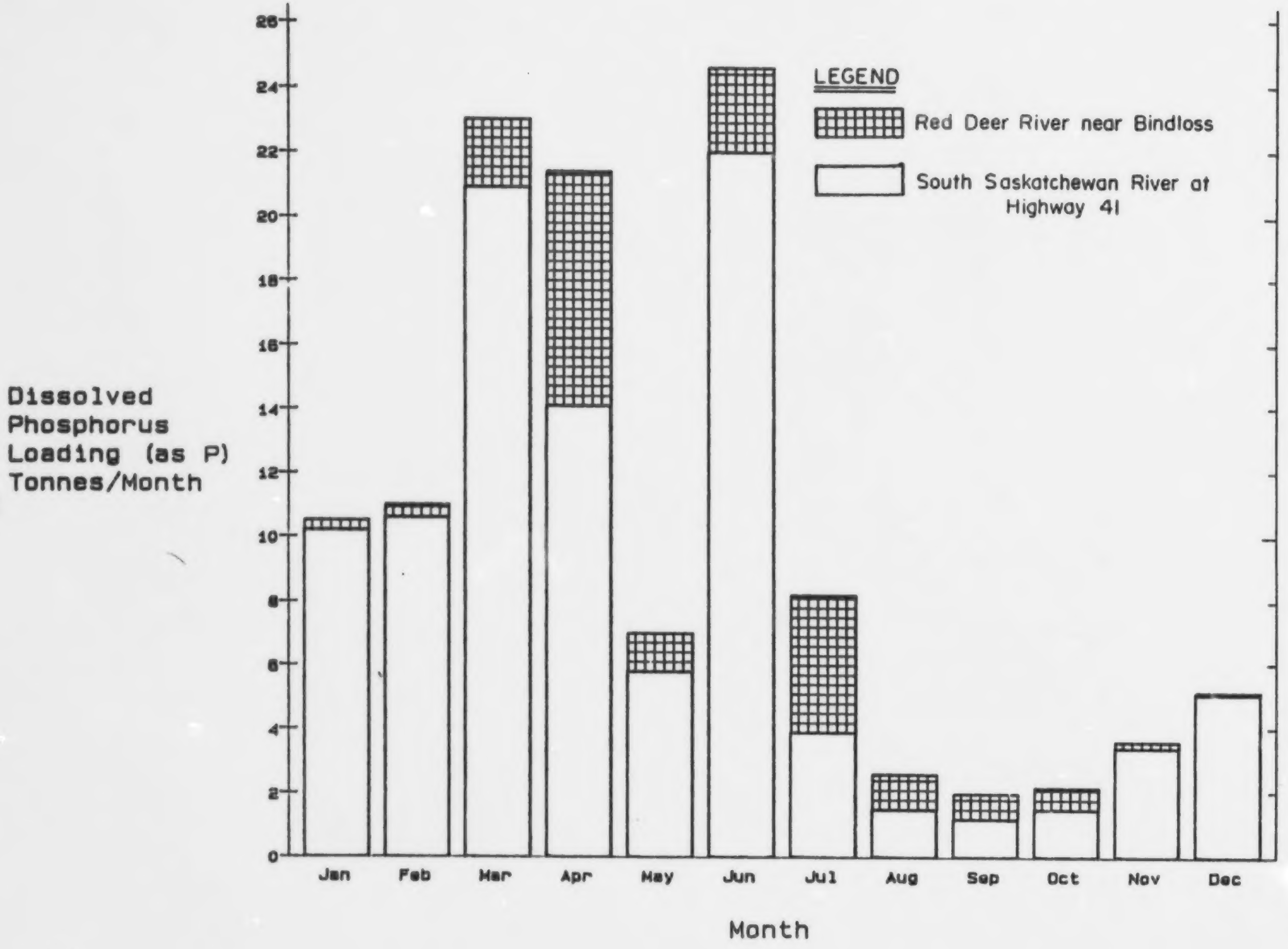


Figure 19 : MONTHLY MEAN DISSOLVED PHOSPHORUS LOADING INTO LAKE DIEFENBAKER, 1975 - 1985

Accurate DP loading estimates are likely achievable through the present monthly monitoring frequency. Any future increases in frequency or replication should key on the SSR site which delivers, on average, 83% of DP loading into Lake Diefenbaker. The major DP loading months, as mentioned previously, are January-July.

(b) Intensive Monitoring at Lemsford Ferry (1985)

Intensive monitoring of nutrient parameters was initiated at Lemsford Ferry in late 1984 for two purposes. These were to achieve increased accuracy in phosphorus loading estimates into Lake Diefenbaker through increased frequency of sampling, and to determine through comparison whether loading estimates based on monthly monitoring results from the SSR and RDR could be relied upon to provide this information.

A total of 45 samples for TP and DP were collected at Lemsford Ferry during 1985. The time between sampling ranged from 3 days to 19 days, with an average of 8 days. The 1985 TP loading calculated from the Lemsford Ferry data was 814 tonnes/annum. This compares with a total of 848 tonnes TP based on tributary loading (Table 5). The 1985 DP loadings based on Lemsford Ferry and the tributaries were 73 tonnes and 62 tonnes, respectively. The DP/TP percentages for 1985 were slightly lower than the 1975-1985 mean (11%), with Lemsford Ferry at 9% and the combined tributaries at 7%.

The daily TP loading rates for Lemsford Ferry (with the combined tributaries overlayed) are shown graphically in Figure 20. Major TP loading events occurred in April, June and September. The April and June events are typical of the period 1975-1985 (Figure 18). The September loading reflected trimodal hydrology. The highest mean daily discharge on the dates of sampling occurred on September 18, 1985 (538 m^3/sec).

It is significant that the combined daily TP daily loading rates from the tributary steams closely overlay the Lemsford Ferry rate curve. This leads strength to the assumption that loss or gain of TP is minimal in the 75 kilometre reach between the monthly monitoring locations and Lemsford Ferry. It can be seen that the loading rates calculated from SSR and RDR tend to cut off the peaks and elevate the valleys present in the Lemsford Ferry calculations. The net effect of this smoothing,

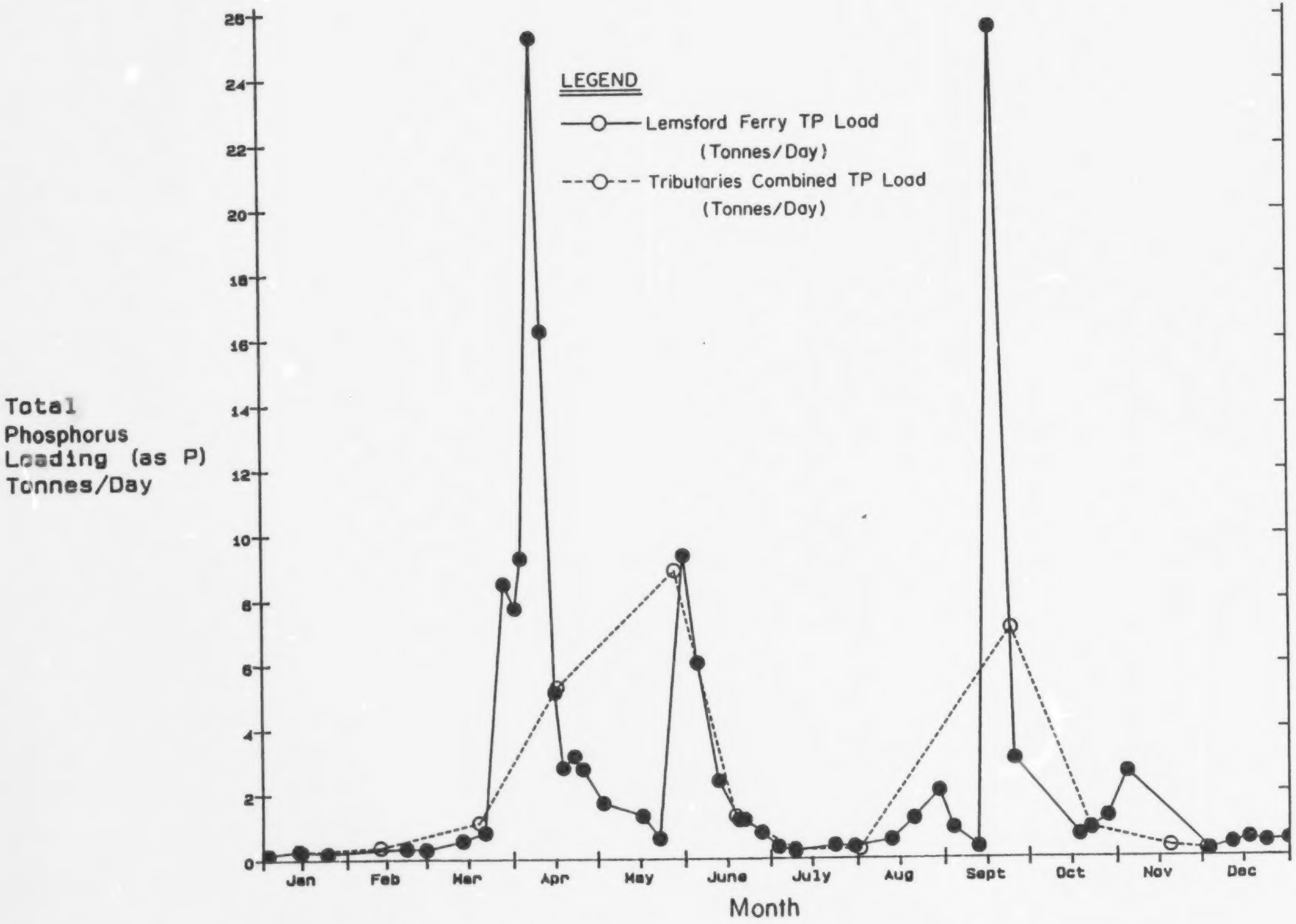


Figure 20 : MEAN DAILY TOTAL PHOSPHORUS LOADING AT LEMSFORD FERRY, 1985.

however, was minimal when the annual loadings (848 tonnes, 814 tonnes) are compared. This is in part due to the "narrow" nature of the major loading events. During years with higher discharge, the difference in TP loading estimates between n=12 and n=45 would be expected to be much larger.

Lemsford seasonal loading of DP in 1985 (Figure 21) was similar to the 1975-1985 mean loading shown in Figure 19, with the exception of June when no major transport occurred. The high flows during September, 1985 did not produce a coexistent increase in DP loading.

The DP loading curve based on SSR and RDR closely parallels the Lemsford Ferry results with the exception of the major loading event in March-April. It can be seen that the tributary stations were sampled on the rising and falling limbs of this event. This largely explains why the DP loading estimate based on SSR and RDR were somewhat lower than that from Lemsford Ferry (62 tonnes, 73 tonnes). As was the case with TP loading, the DP loading on all 1985 dates of sampling at SSR and RDR was very close to that measured at Lemsford. This again lends strength to the argument that composite

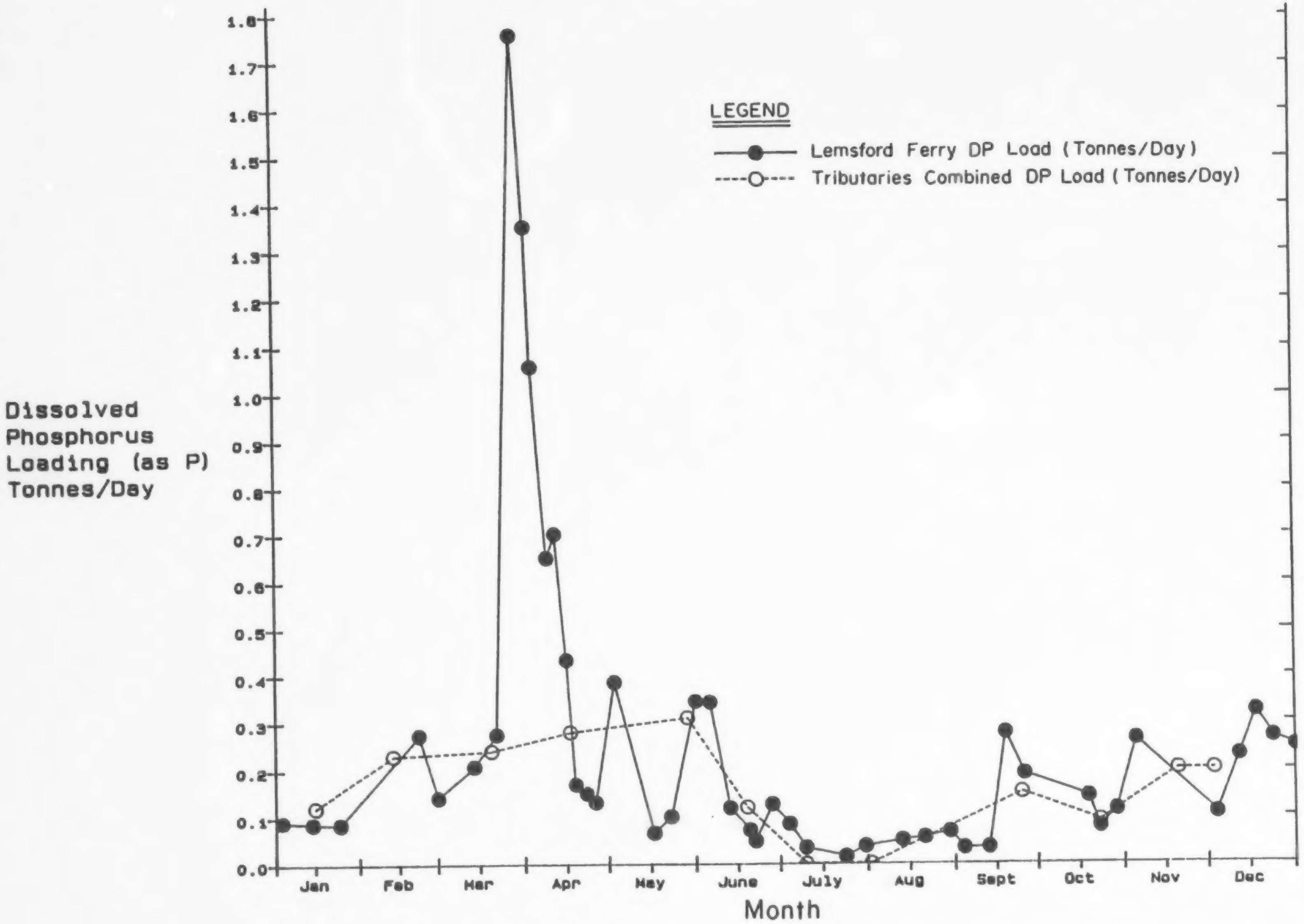


Figure 21 : MEAN SEASONAL DISSOLVED PHOSPHORUS LOADING AT LEMSFORD FERRY, 1985

phosphorus loads from the above-confluence stations are representative of loading further downstream.

To summarize, 1985 annual P-loading estimates based on two independent sources, monthly (n=12) sampling at SSR and RDR, and more frequent (n=45) sampling at Lemford Ferry, were found to be similar. If one considers the Lemsford Ferry results to be accurate, the SSR and RDR estimate of TP loading was 4% higher, and the DP loading estimates was 15% low. Error of this magnitude is likely acceptable to those involved with management of eutrophication in Lake Diefenbaker. It is felt, however, that the close comparability of loading estimates for 1985 was largely due to relatively low discharge during the year, which reduced the magnitude of major P loading events, and hence the chance to greatly over or underestimate loading by sampling too infrequently.

The data clearly illustrated (Figure 19) that composite SSR and RDR phosphorus loadings on all dates of sampling during 1985 were very similar to those measured at Lemsford Ferry, leading to the conclusion that change in P loading in the reach between stations was minimal. Future comparisons of

1986 and 1987 P loading results from Lemsford Ferry and SSR and RDR will be undertaken to test the validity of this conclusion.

Based on the 1985 results it is probable that acceptable estimates of phosphorus loading into Lake Diefenbaker can be achieved at the SSR and RDR stations. Depending upon the level of accuracy required, however, frequency of sampling will have to be altered to achieve better definition of major loading seasons, especially in years where above average discharge is anticipated.

3.2.3 Major Ions and Physical Parameters

Table 7 presents a summary of study period and historic results for the river monitoring stations. At the Red Deer River station (R1), the study period mean concentration of total dissolved solids (TDS) (236 mg/L) was substantially lower than the historic mean (302 mg/L). R1 concentrations of all ions contributing to TDS were lower than or equal to the historic mean. A specific conductance of 319 uS/cm was recorded at R1 in September, 1984, the lowest on record for the site. All other results were within the historical ranges.

Table 7

Summary of Study Period and Historic Results for Major Ions and Physical Parameters, River Monitoring Stations

	South Sask. River at Highway 41		Red Deer River Near Bindloss		South Sask. River at Leader		South Sask. River at Lemsford	South Sask. River at Outlook
	1984-85	1974-85 (1)	1984-85	1974-85 (1)	1984-85	1974-85 (2)	1984-85	1978-85 (3)
Number of Samples	24	137	24	139	24	74	24	73
pH (mean) pH units	8.1	8.2	8.0	8.1	8.1	8.1	8.1	8.1
(max)	8.5	9.0	8.3	8.4	8.3	8.8	8.5	8.5
(min)	7.5	7.5	7.5	7.4	7.6	7.2	7.6	7.3
Spec Cond (mean) uS/cm	384.	396.	411.	490.	394.	403.	398.	414.
(max)	501.	594.	504.	916.	510.	700.	508.	500.
(min)	281.	258.	319.	323.	317.	250.	318.	280.
Calcium (mean) mg/L	38.3	42.5	42.2	52.8	40.3	44.8	40.7	42.4
(max)	58.2	76.8	64.2	103.	60.0	68.0	60.4	56.0
(min)	27.2	23.5	29.0	28.3	30.0	26.0	29.8	13.0
Magnesium (mean) mg/L	14.9	16.2	15.0	20.2	15.0	17.5	15.1	18.8
(max)	18.8	25.4	19.7	40.8	18.3	27.0	18.7	38.0
(min)	11.2	9.7	10.2	10.2	11.1	12.2	11.5	12.0
Potassium (mean) mg/L	1.8	1.8	2.8	2.8	2.2	3.1	2.2	3.6
(max)	2.3	6.0	5.6	8.6	4.1	7.0	3.7	18.0
(min)	0.93	0.6	1.6	1.4	1.3	1.3	1.3	2.0
Sodium (mean) mg/L	18.5	16.5	21.4	27.5	19.5	21.0	20.1	20.4
(max)	32.3	32.4	28.1	68.5	28.4	36.0	29.4	28.0
(min)	7.7	5.3	13.5	11.0	11.0	8.0	11.2	14.0
Chloride (mean) mg/L	6.1	5.4	4.2	5.3	5.1	6.7	5.1	6.1
(max)	9.7	15.8	5.3	45.0	7.0	20.0	7.1	16.0
(min)	2.4	<0.1	3.4	<0.1	3.0	0.5	2.8	1.0
Sulphate (mean) mg/L	64.7	58.0	57.2	69.0	59.0	64.2	61.9	66.5
(max)	102.	103.	77.6	135.	82.7	81.4	85.4	88.0
(min)	34.6	24.0	34.2	24.0	30.8	40.9	40.0	50.0
T. Hardness (mean) mg/L	157.	172.	167.	223.	162.	188.	164.	184.
(max)	217.	296.	241.	425.	224.	244.	227.	261.
(min)	120.	110.	126.	105.	132.	156.	133.	144.

Table 7 (continued)

Summary of Study Period and Historic Results for Major Ions and Physical Parameters, River Monitoring Stations

		South Sask. River at Highway 41		Red Deer River Near Bindloss		South Sask. River at Leader		South Sask. River at Lemsford	South Sask. River at Outlook
		1984-85	1974-85 (1)	1984-85	1974-85 (1)	1984-85	1974-85 (2)	1984-85	1978-85 (3)
Alkalinity	(mean) mg/L	127.	135.	157.	194.	143.	151.	146.	152.
	(max)	175.	227.	217.	417.	184.	250.	190.	176.
	(min)	106.	87.0	125.	40.4	123.	110.	120.	124.
TDS	(mean) mg/L	216.	220.	236.	302.	224.		228.	
	(max)	275.	364.	272.	589.	273.	(4)	280.	(4)
	(min)	153.	115.	209.	182.	177.		171.	

(1) Environment Canada stations monitored monthly for the Prairie Provinces Water Board since 1974.

(2) Saskatchewan Environment and Public Safety monitoring station. Monitored since 1978, with expansion to include most major ions in 1983.

(3) Saskatchewan Environment and Public Safety monitoring station. Major ions monitored since 1978.

(4) Data not available.

Mean TDS at the south Saskatchewan River at Highway 41 (R2) was only slightly lower during the study period (216 mg/L) than over the period of record (220 mg/L). Mean concentrations of four parameters (Ca, Mg, Total Alkalinity, Total Hardness) were slightly lower than period of record, and concentrations of four parameters (Na, Cl, SO_4, K) were equivalent or higher. All results from R2 were within the historical ranges.

Sampling of the river locations during the study period was scheduled to reflect river hydrology. Of eight sampling trips made during 1984-85, four were made during spring, one in summer, two in fall, and one in winter. The study period data are therefore biased toward the spring period, when freshet dilutes the concentrations of many dissolved solids. The bias in sampling schedules was partially balanced by the fact that discharge (and hence dilution) during 1984 and 1985 was below average. During the two year period 1984-85, total discharges at R1 and R2 were 93% and 68% of normal, respectively. Thus the spring bias effect was more dominant at R1 than at R2, as evidenced by the TDS results.

Of the two Alberta tributary sites, the Red Deer River (R1) tends to be more highly mineralized than the South Saskatchewan River at Highway 41 (R2). Mean TDS at R1 exceeded R2 by 9% during the study (236 mg/L, 216 mg/L respectively), and by 37% over the period of record (302 mg/L, 220 mg/L).

A flow-weighted composite of the two upstream stations is produced at Leader (R3), which had a study mean TDS of 224 mg/L. Total discharge during 1984-85 at R2 (5,180,000 dam^3) exceeded that at R1 (2,235,000 dam^3) by a factor of 5:2. As was the case at R1, mean study concentrations at R3 were lower than period of record concentrations for all major ions.

The order of predominance of ions during the study was as follows (mean concentration in milliequivalents per litre are noted):

Cations:

R1: Ca (2.11) > Mg (1.24) > Na (0.93) > K (0.07) Total 4.35 meq/L
R2: Ca (1.92) > Mg (1.23) > Na (0.80) > K (0.05) Total 4.00 meq/L
R3: Ca (2.02) > Mg (1.24) > Na (0.85) > K (0.06) Total 4.17 meq/L
R4: Ca (2.04) > Mg (1.25) > Na (0.87) > K (0.06) Total 4.22 meq/L
R4*:Ca (2.24) > Mg (1.45) > Na (0.91) > K (0.08) Total 4.68 meq/L
R7*:Ca (2.12) > Mg (1.55) > Na (0.89) > K (0.09) Total 4.65 meq/L

Anions:

R1: HCO_3 (3.13) > SO_4 (1.19) > Cl (0.12) Total 4.44 meq/L
R2: HCO_3 (2.54) > SO_4 (1.35) > Cl (0.17) Total 4.06 meq/L
R3: HCO_3 (2.85) > SO_4 (1.23) > Cl (0.14) Total 4.22 meq/L
R4: HCO_3 (2.92) > SO_4 (1.29) > Cl (0.14) Total 4.35 meq/L
R4*:HCO_3 (3.02) > SO_4 (1.34) > Cl (0.19) Total 4.55 meq/L
R7*:HCO_3 (3.03) > SO_4 (1.39) > Cl (0.17) Total 4.59 meq/L

R4*, R7*: Monthly monitoring results, Leader and Outlook 1978-1985.

All locations are seen to be of a similar calcium-magnesium carbonate type, with the same orders of abundance of major ions. A slight increase in the concentration of most ions was apparent in the 31 river kilometres between Leader and Lemsford. Little change in concentration occurred in the 330 kilometre reach between Leader (R4) and Outlook (R7), which includes Lake Diefenbaker. Using the period of record statistics the mean concentration (cations + anions) was approximately 9.23 meq/L (R4) and 9.24 meq/L (R7). This agrees with the data in Table 19, Chapter 4, which show the waters of Lake Diefenbaker to be relatively homogeneous with respect to the concentration of major ions.

Spatial plots of study and period of record mean concentration and range for four parameters are presented in Figures 22 and 23. It can be seen that the range of study period results (circles) generally fall within the boundaries defined by the long-term monitoring programs (triangles). Of the tributary sources, the waters of the Red Deer River are seen to have higher and more variable concentrations than the upper South Saskatchewan River. It is evident that very little change in concentration occurs between Leader and Outlook. Perhaps most illuminating is the narrowing in concentration range moving downstream through Lake Diefenbaker. This is most apparent in the plots of specific conductance and total alkalinity. Variability in specific conductance is seen to be relatively high at Cabri Park and Saskatchewan Landing, and lower from Herbert Ferry downstream. Total alkalinity shows low variability from the Herbert Ferry site downstream. The location of the precise point where the South Saskatchewan River becomes Lake Diefenbaker has long been argued. In terms of these parameters, lake characteristics, as determined by relatively low concentration variability, begin to outweigh river characteristics in the Saskatchewan Landing-Herbert Ferry reach.

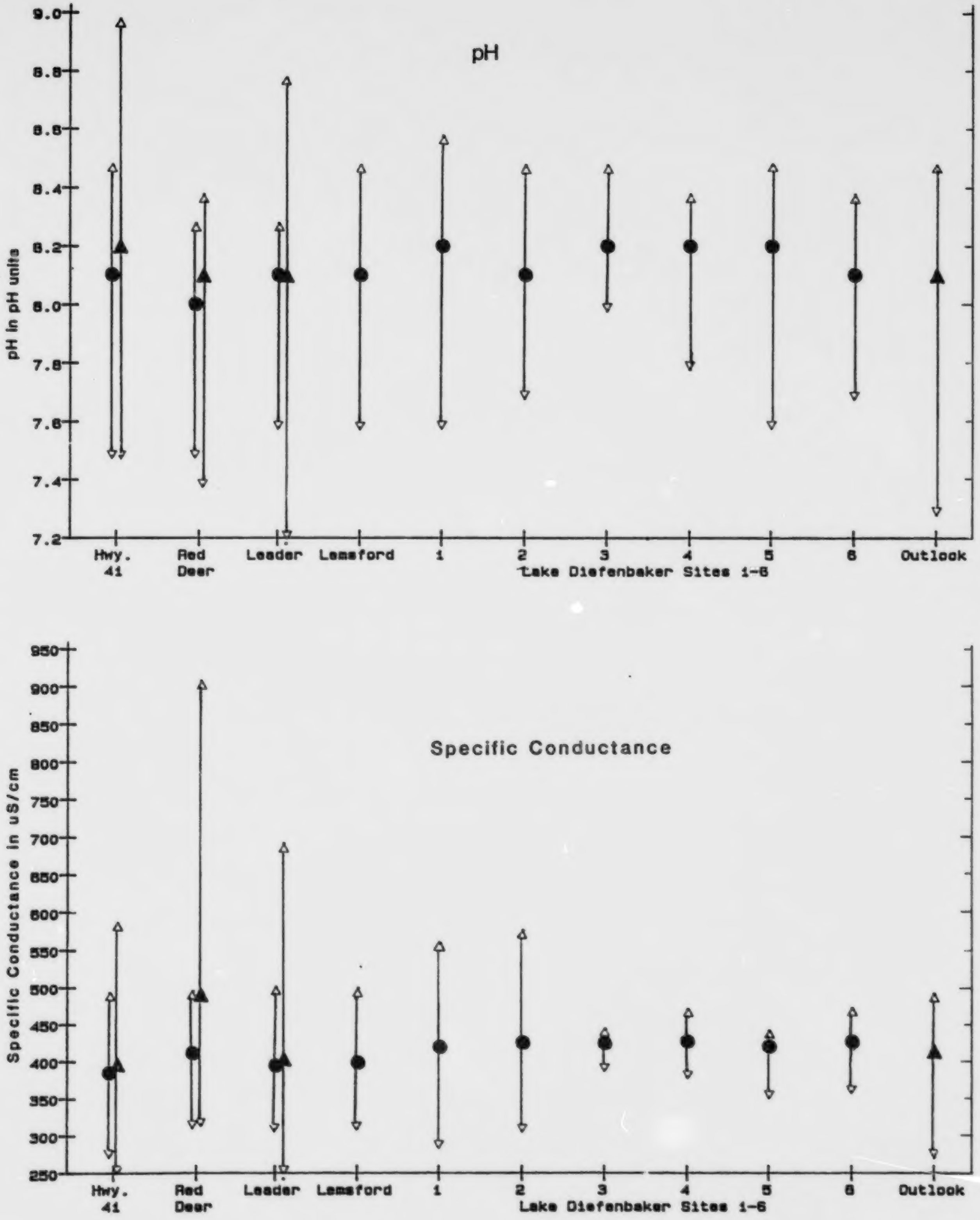


Figure 22: SPATIAL PLOT OF STUDY PERIOD (CIRCLES) AND PERIOD OF RECORD (TRIANGLES) MEAN AND RANGE FOR pH AND SPECIFIC CONDUCTANCE.

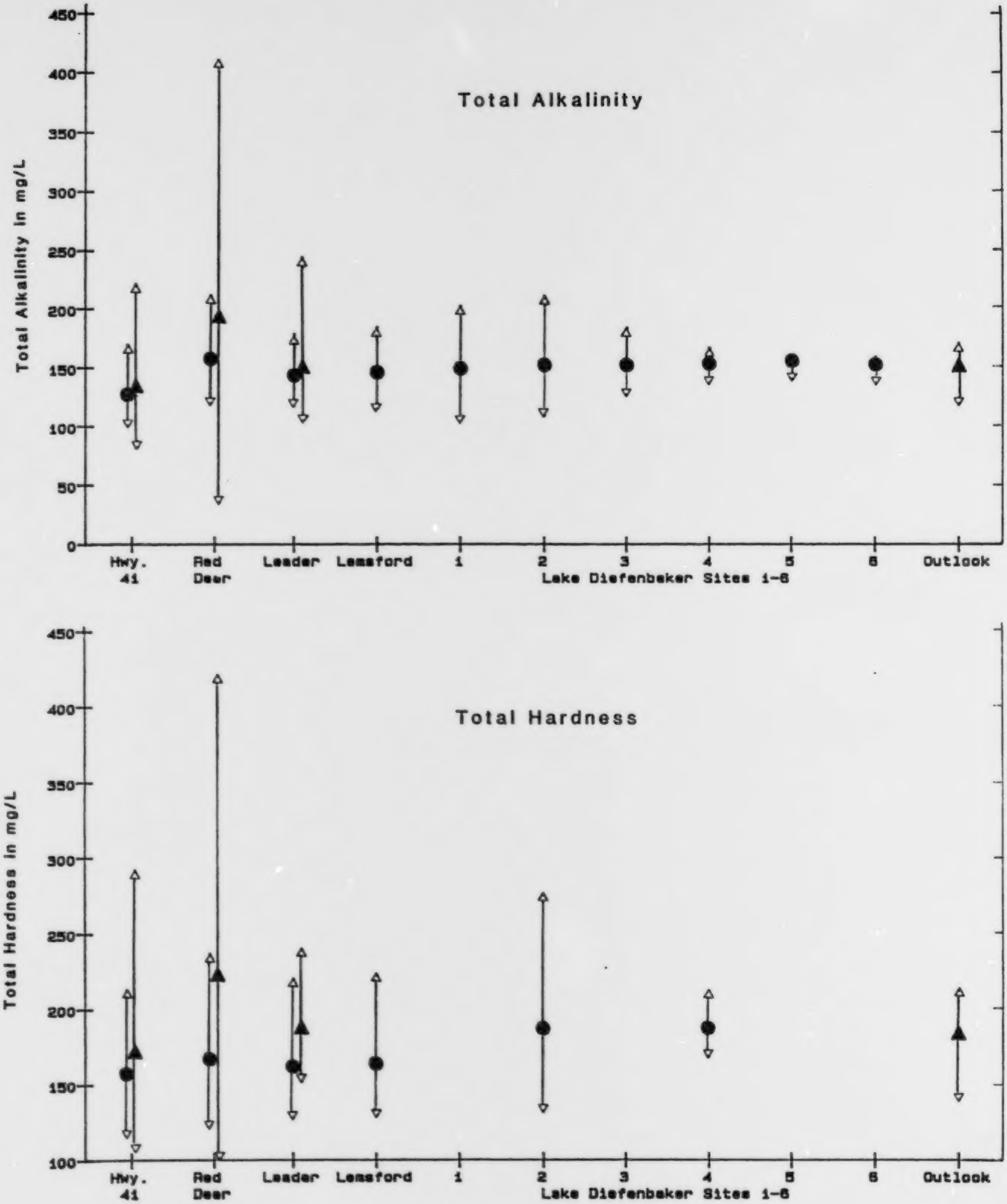


Figure 23: SPATIAL PLOT OF STUDY PERIOD (CIRCLES) AND PERIOD OF RECORD (TRIANGLES) MEAN AND RANGE FOR TOTAL ALKALINITY AND TOTAL HARDNESS.

Study period seasonal plots for four parameters with best second order fits are presented in Figures 24 to 27. In each Figure, the upper plot contains best seasonal fit lines for the four river stations located above Lake Diefenbaker, based upon data collected during the study only. The lower plot compares seasonal fits for monthly data collected at Leader and Outlook during 1978-1985.

The sites above Lake Diefenbaker display the same annual trend (summer-low, winter-high) for most major ions. This annual trend is typical of most streams, reflecting the increased proportion of more highly mineralized ground water present during the colder months. pH at all river sites showed a summer-high winter-low annual trend. This is caused, among other factors, by reduced plant photosynthesis during winter, resulting in a decrease in plant uptake of carbon dioxide, which forms a weak acid when in solution. Seasonal trends for potassium were mixed, with R1 tending to show a summer-high winter-low trend, and the main stem sites showing the opposite or little trend.

The linear nature of the trend curves at Outlook shows the impounding effects of Lake Diefenbaker, indicating that the waters of several seasons are mixed by the time they pass through Gardiner Dam.

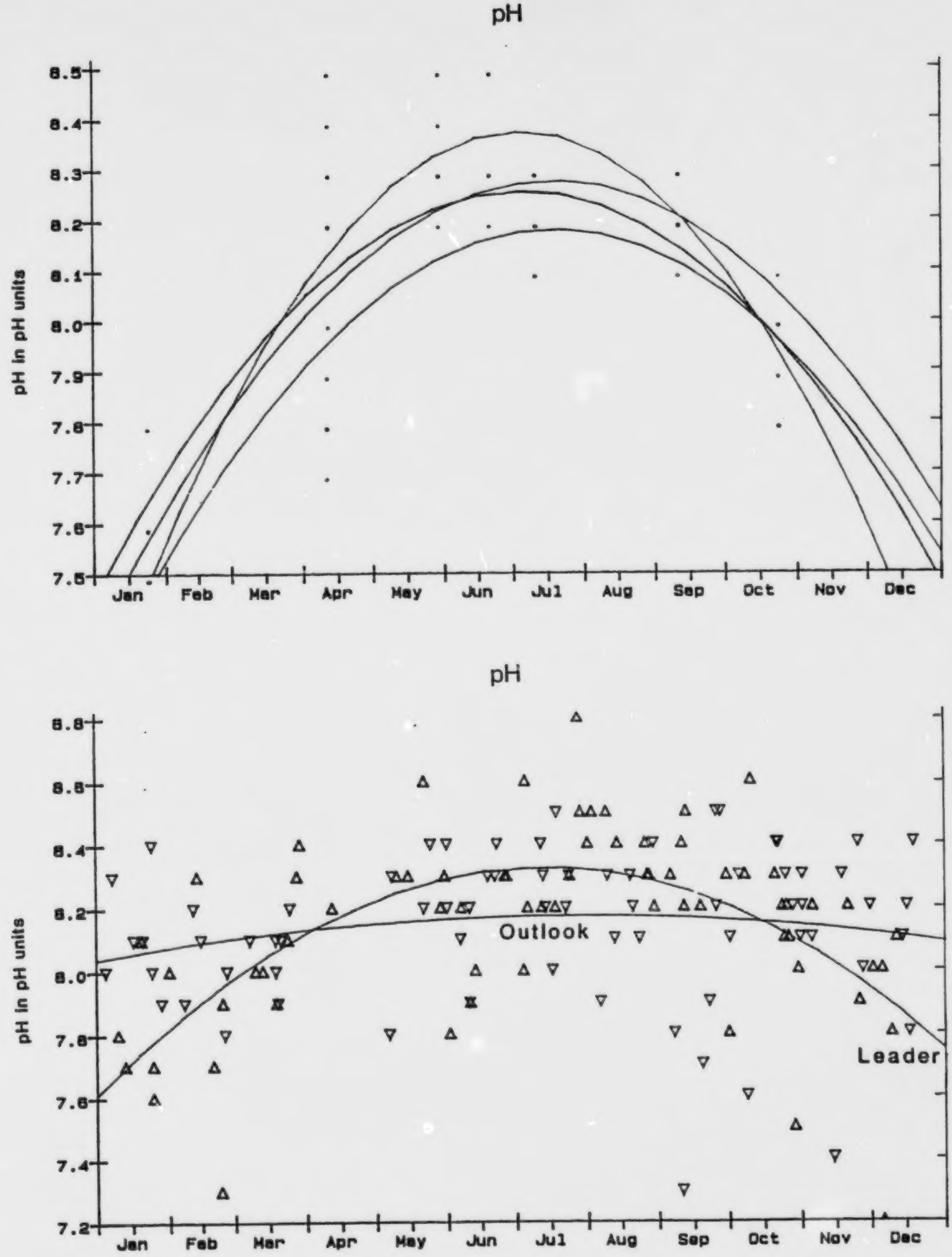
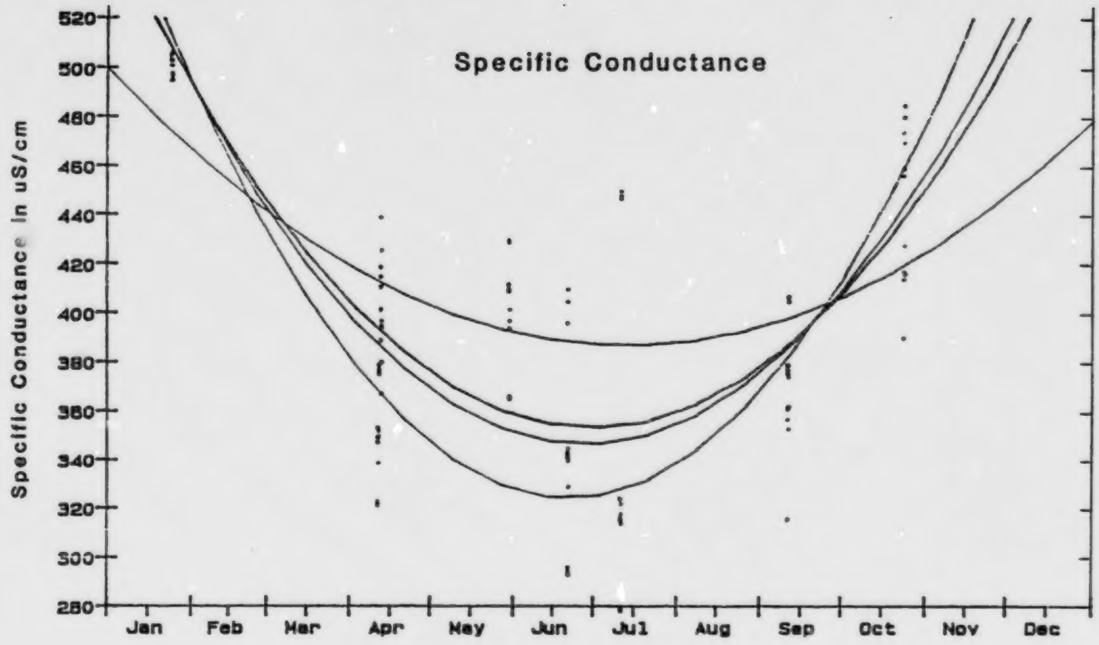


Figure 24 : BEST SECOND ORDER SEASONAL FIT FOR pH AT STATIONS ABOVE LAKE DIEFENBAKER, 1984 - 1985 (TOP) AND AT LEADER AND OUTLOOK, 1978 - 1985 (BOTTOM).



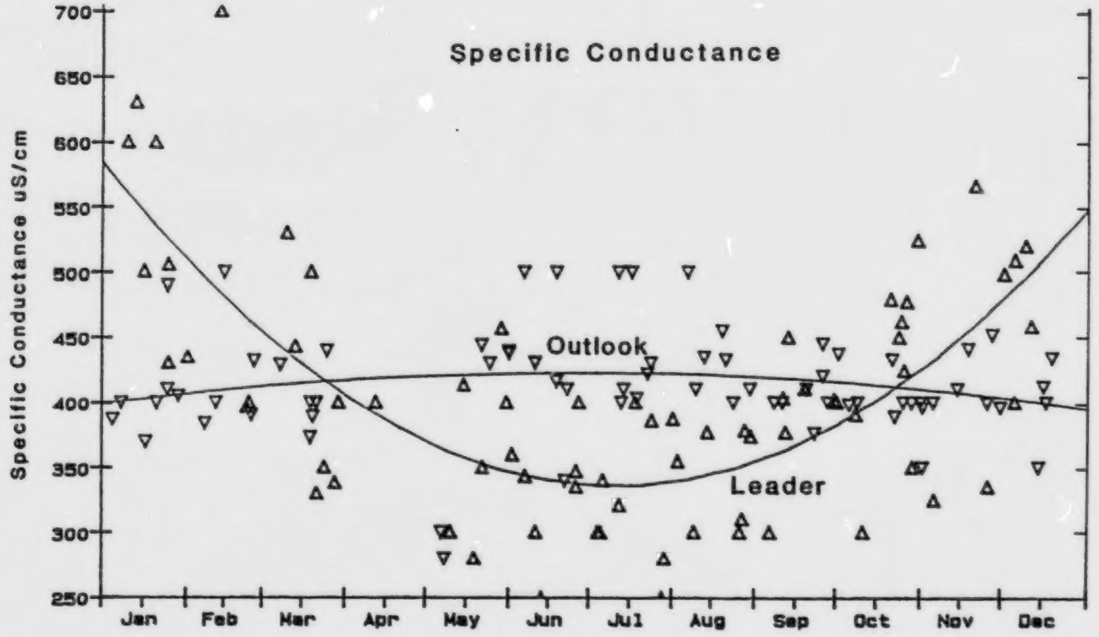


Figure 25: BEST SECOND ORDER SEASONAL FIT FOR SPECIFIC CONDUCTANCE AT STATIONS ABOVE LAKE DIEFENBAKER, 1984 - 1985 (TOP) AND AT LEADER AND OUTLOOK, 1978 - 1985 (BOTTOM).

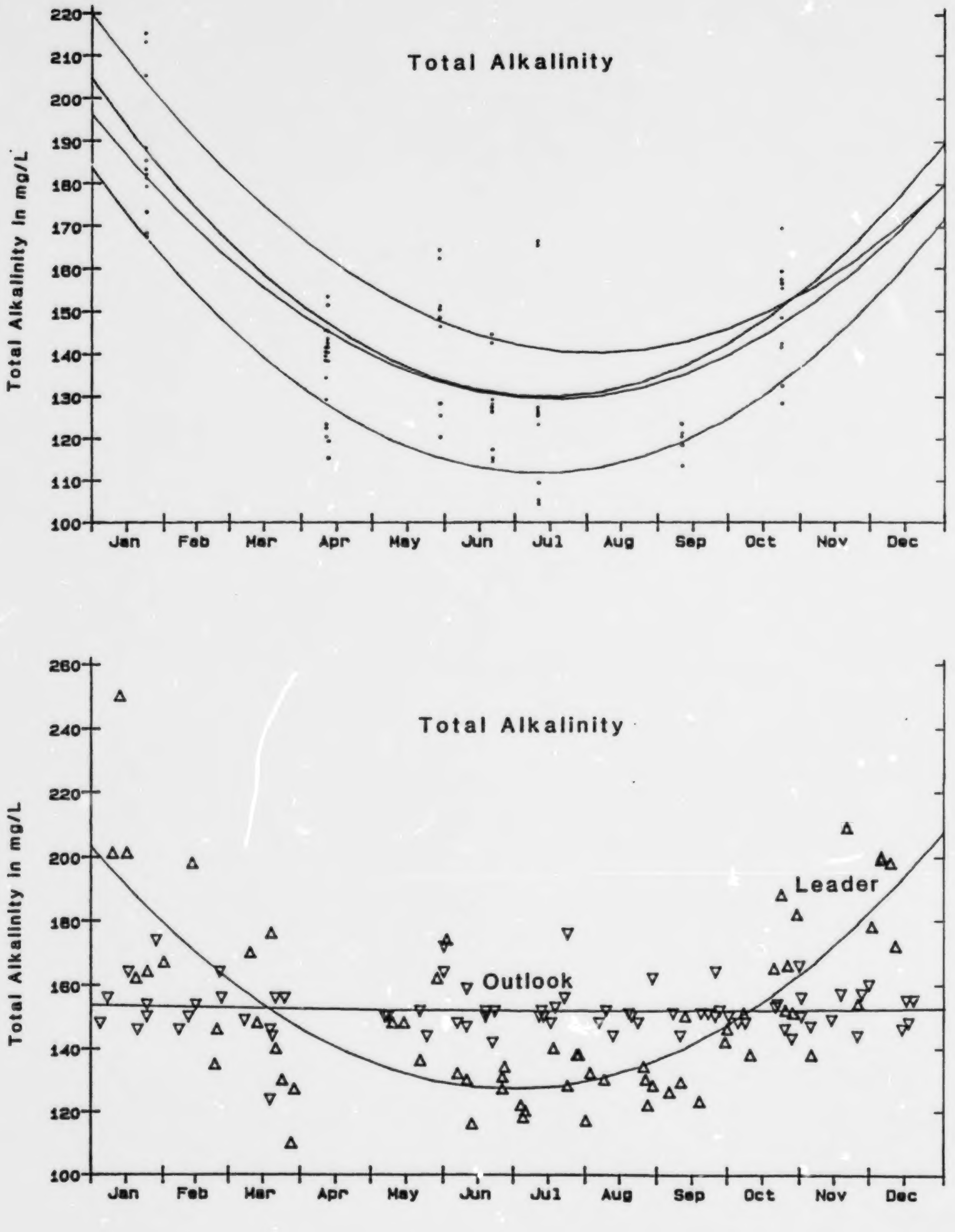
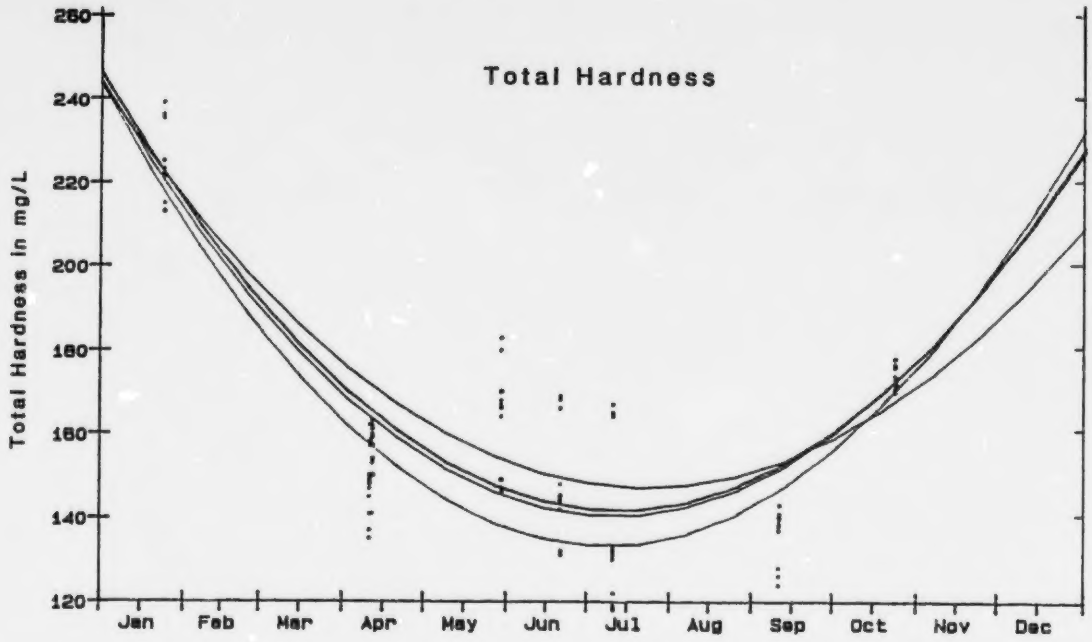


Figure 26 : BEST SECOND ORDER SEASONAL FIT FOR TOTAL ALKALINITY AT STATIONS ABOVE LAKE DIEFENBAKER , 1984 - 1985 (TOP) AND AT LEADER AND OUTLOOK , 1978 - 1985 (BOTTOM).



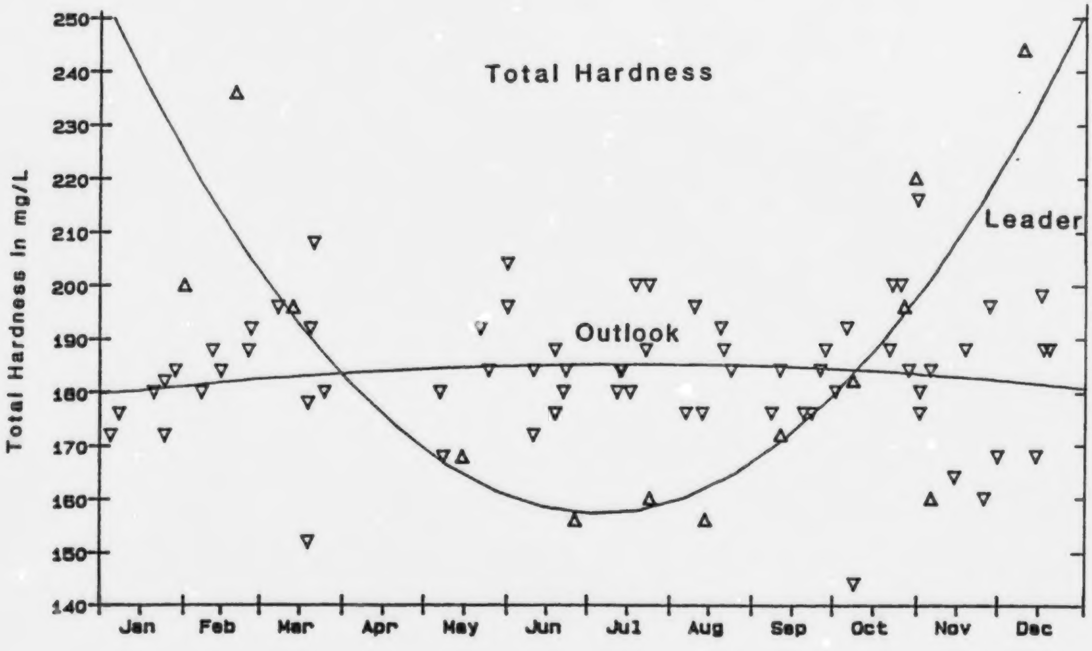


Figure 27 : BEST SECOND ORDER SEASONAL FIT FOR TOTAL HARDNESS AT STATIONS ABOVE LAKE DIEFENBAKER, 1984 - 1985 (TOP) AND AT LEADER AND OUTLOOK, 1978 - 1985 (BOTTOM).

Table 8 contains existing municipal drinking water objectives for major ions and physical parameters (Saskatchewan Environment, 1980) and the Canadian Water Quality Guidelines (CCREM, 1981) designed for the protection of specific uses. Also tabulated are highest concentrations recorded during the period of record within the study area (lake and river).

It can be seen that there have been no exceedences of most sensitive use objectives and guidelines during the period of record, which dates to 1974. The differential between most-sensitive objectives and period of record maxima are relatively large, leading to the conclusion that the likelihood of exceedence, given the present patterns of use within Alberta and Saskatchewan, is low in the short or medium term.

Table 8

Saskatchewan Water Quality Objectives for Surface Waters and Municipal Drinking Supplies (pH and Major Ions)

Parameter	Protected Use	Objective (Source)	Maximum on Record* (Site
TDS	Irrigation	700 mg/L (1)	589 mg/L (Bindloss)
	Livestock	1000 mg/L (1)	
	Drinking	1500 mg/L (2)	
Chloride	Irrigation	100 mg/L (1)	45 mg/L (Bindloss)
Fluoride	Irrigation	1 mg/L (1)	0.36 mg/L (Highway 41)
	Drinking	1.5 mg/L (2)	
	Livestock	2 mg/L (1)	
Alkalinity	Drinking	500 mg/L (1)	417 mg/L (Bindloss)
Sulphate	Drinking	500 mg/L (2)	135 mg/L (Bindloss)
	Livestock	1000 mg/L (1)	
Sodium	Irrigation	100 mg/L (1)	68.5 mg/L (Bindloss)
	Drinking	300 mg/L (2)	
SAR	Irrigation	<4.0 for most sensitive soils (1)	3.5 (note 3)
Magnesium	Drinking	200 mg/L (2)	40.8 mg/L (Bindloss)
Total Hardness	Drinking	800 mg/L (2)	425 mg/L (Bindloss)
(Mg and NA) + SO_4	Drinking	1000 mg/L (2)	244 mg/L (note 4)
pH	Drinking	7.0-9.5 (2)	7.2-9.0

(*) Maximum concentration reported during period of record (all river and lake stations).

(1) From Canadian Water Quality Guidelines, Canadian Council of Resource and Environment Ministers, Ottawa, 1987.

(2) From Saskatchewan Environment, Water Pollution Control Branch: Municipal Water Quality Objectives, June 1980.

(3) SAR = .043 Na / (.025 Ca + .041 Mg)1/2. The SAR of 3.5 is based on the highest Na (68.5 mg/L) and the lowest Ca (13 mg/L) and Mg (9.7 mg/L) on record (all sites). Results were not from a single sample.

(4) Based on the highest Mg (40.8 mg/L), Na (68.5 mg/L), and SO_4 (135 mg/L) on record. Results may not have occurred in a single sample.

4. LAKE CHEMISTRY

4.1 Assessment Methodology

4.1.1 Sampling Sites

Saskatchewan Environment and Public Safety has monitored several stations on Lake Diefenbaker since the mid 1970s. Sites at Saskatchewan Landing, Riverhurst, Douglas and Danielson were retained for the 1984-85 study. In addition, sampling stations opposite Herbert Ferry Regional Park and opposite Cabri Regional Park were added to fill the information gap for the area between the existing stations.

The location of the lake sampling sites are shown on Figure 1 and Table 9 provides a brief description. Station numbers have been frequently used in referring to the lake sampling sites.

Table 9

Lake Diefenbaker Mid-Lake Sampling Sites, 1984-85

Station No.	Name
1.	Opposite Cabri Regional Park
2.	Opposite Saskatchewan Landing Provincial Park
3.	Opposite Herbert Ferry Regional Park
4.	Riverhurst Ferry Crossing
5.	Opposite Douglas Provincial Park
6.	Opposite Danielson Provincial Park

4.1.2 Sampling Schedule and Field Methods

Lake monitoring commenced on July 3, 1984 and was completed by June 24, 1985. The six lake sites were sampled a total of fourteen times during this period at approximately three week intervals (see Table 10).

Field methods for the lake study followed Saskatchewan Environment and Public Safety standard procedures as described in the Water Pollution Control Branch Field Procedures Manual (1984). Field filtration was performed for dissolved nitrogen, dissolved ortho phosphorus and dissolved phosphorus samples following procedures outlined in the Environment Canada field procedures manual entitled Sampling for Water Quality (1983).

Samples for algal identification and enumeration were composites from one metre below the surface, half the photic zone depth and one metre above the bottom of the photic zone. The photic zone is defined as twice the secchi depth. Secchi depths were determined with the aid of a viewing tube during open water months. Mean Secchi depths obtained during the summer were used to determine the algae sampling depth regime during periods of ice cover.

Dissolved oxygen and temperature measurements were performed simultaneously during each visit to Lake Diefenbaker, using a YSI Model 57 portable DO meter. Readings were done at 1 metre intervals to provide depth profiles. Continuous dissolved oxygen and temperature records were obtained at one near-shore station with an Esterline Angus portable strip chart recorder. Water samples were composited based on conditions related to the location of the thermocline (Tones, 1984).

4.1.3 Parameters

A list of parameters sampled during the Lake Diefenbaker study along with some comments on their significance is provided on Table 10.

Table 10

Lake Monitoring Details, 1984-85

Dates	Parameters	Significance
July 3, 16, 30; Aug. 13, 27; Sept. 17; Oct. 9; Jan. 14; Feb. 4, 18; Mar. 11; May 13; June 3, 24	(i) Field Measurements	
	- dissolved oxygen	- oxygen dissolved in water; fundamental requirement of life for aquatic organisms
	- temperature	- self-explanatory
	- secchi depth (SD)	- procedure used to determine water transparency
	(ii) Nutrients and Related Parameters	
	- total kjehdahl nitrogen (TKN)	- measures both ammonia and organic nitrogen

Table 10 (continued)

Lake Monitoring Details, 1984-85

Dates	Parameters	Significance
	- nitrate-nitrite nitrogen (NO_3-NO_2)	- soluble nitrogen resulting from the oxidation of nitrogen compounds
	- total nitrogen (TN)	- see Table 3
	- dissolved nitrogen (DN)	- see Table 3
	- particulate nitrogen (PN)	- see Table 3
	- total phosphorus (TP)	- see Table 3
	- orthophosphorus (ORTHO-P)	- dissolved phosphate ion; major limiting nutrient for algae growth
	- dissolved phosphorus (DP)	- see Table 3
	- dissolved organic carbon (DOC)	- see Table 3
	- chlorophyll "a"	- the colouring pigment of green parts of plants; biomass indicator
	(iii) Major Ions and Physical and Physical Parameters	
	- major ions	- see Table 3
	- pH	- see Table 3
	- conductivity	- see Table 3
	- total suspended solids (TSS)	- see Table 3
	(iv) Biological Parameters	
	- phytoplankton	- microscopic algae that float in open water of lakes; can be used as an indicator of the trophic status of lakes
	- bacteria - total coliforms (TC) - fecal coliforms (FC) - fecal strep (FS)	- indicators of bacteriological water quality

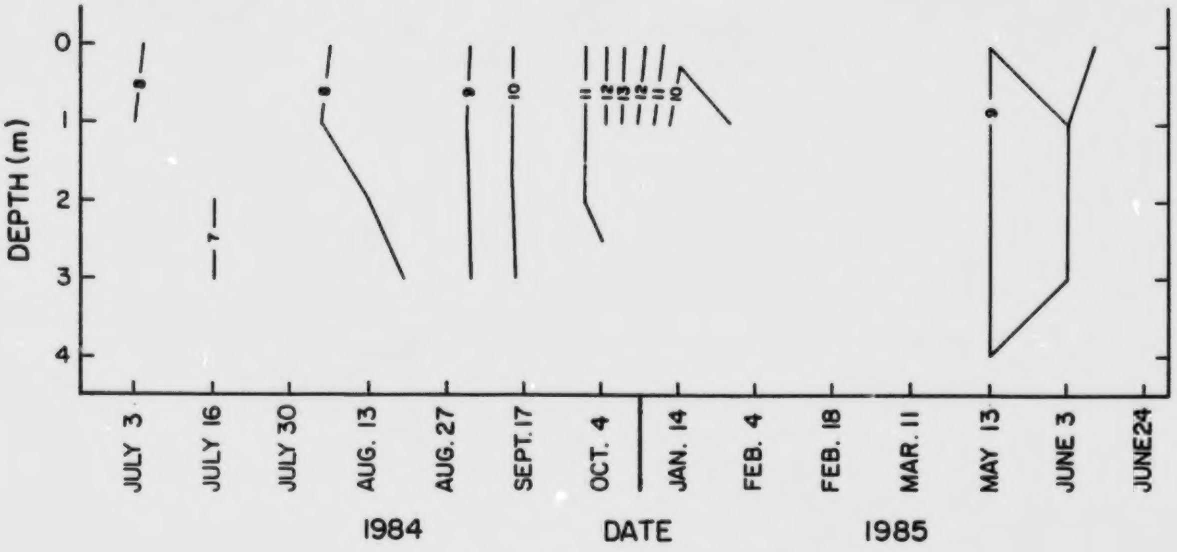
4.2 Results and Discussion

4.2.1 Dissolved Oxygen and Temperature

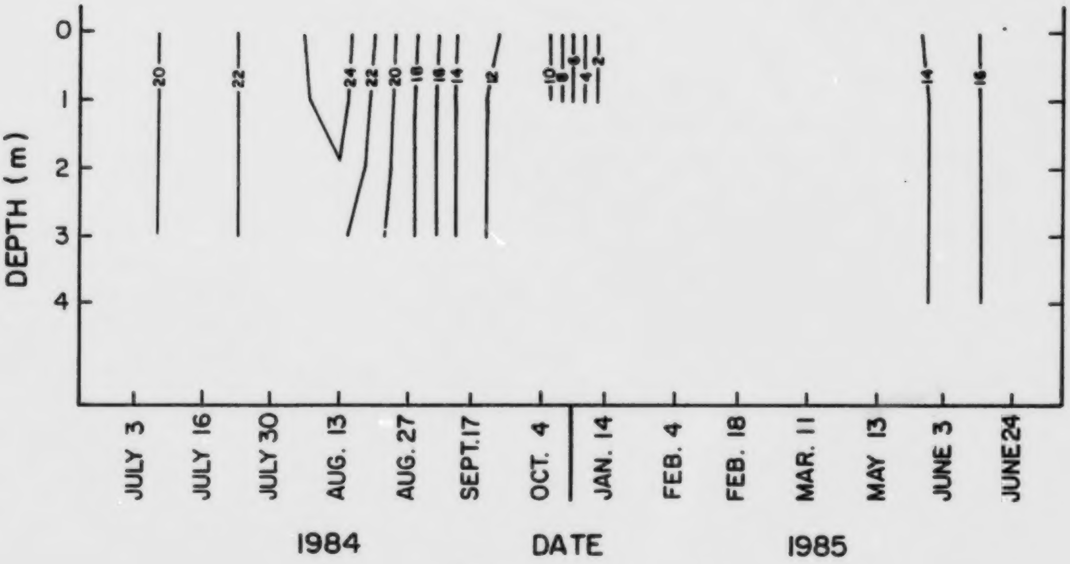
The depth-time isopleth graphs shown in Figures 28 to 33 were derived from the dissolved oxygen (DO) and temperature profiles recorded for the Lake Diefenbaker study. The graphs illustrate, by means of contour lines, the changes that took place in these parameters over depth and sampling date for each station.

Figure 28 shows the depth-time diagrams for the most upstream sampling point on Lake Diefenbaker, Station 1 - Opposite Cabri Regional Park. Hydrometric conditions in this location closely resemble those present in a river rather than a lake situation. The lake here is narrow and quite shallow (generally less than 3 metres deep) with sufficient flow present to reaerate the water and maintain satisfactory DO levels even under ice cover conditions. DO concentrations remained above the surface water quality objective for the duration of the study.

At Station 2 - Opposite Saskatchewan Landing Provincial Park - dissolved oxygen levels were satisfactory for most of the year (Figure 29). The exceptions were the July 16 and July 30, 1984, surveys when DO levels dropped to between 3.0 and 5.0 mg/L below the 9 metre depth, and the August 13 survey when DO levels dipped to 0.8 mg/L at the lake bottom. The lake was thermally stratified at 7.0 metres on July 16 and at 11 metres on July 30, and there was some loss of oxygen at the lower depths.



DISSOLVED OXYGEN (mg/L)



TEMPERATURE (°C)

Figure 28 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN CONCENTRATIONS (UPPER) AND TEMPERATURE (LOWER) FOR LAKE DIEFENBAKER STATION 1, 1984-1985

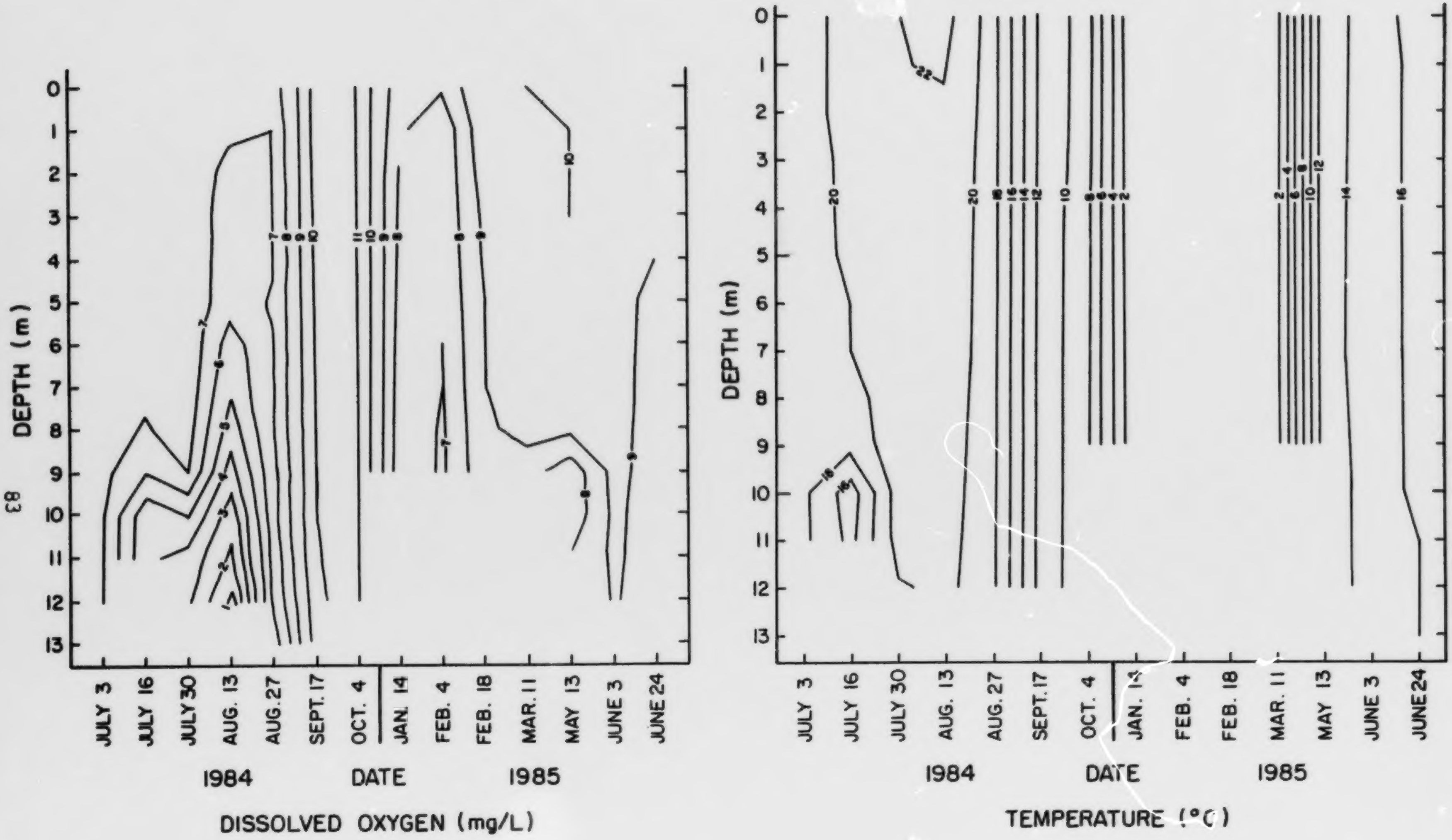


Figure 29 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN (LEFT) AND TEMPERATURE (RIGHT) FOR LAKE DIEFENBAKER STATION 2 , 1984 - 1985

Stratification occurred at Station 3 - Opposite Herbert Ferry Regional Park - during the July 31 and August 14, 1984, surveys (Figure 30). DO levels dropped to 3.1 mg/L near the bottom on July 31 and 0.15 mg/L on August 14. For the remainder of the year the DO levels remained satisfactory for all depths. The thermocline occurred at 16 metres on July 31 and at 9 metres on August 14.

Figure 31 shows an oxygen reduction in the lower hypolimnion (down to 2.7 mg/L) in the results for Station 4 - Riverhurst Ferry Crossing. Here the reduction occurred in late summer and early fall (August 28 and September 17, 1984). This indicates that the fall turnover had not occurred by September 17 or was not yet complete. During fall turnover, oxygen-saturated water is carried deeper into the hypolimnion. This became evident by the October 9 survey when oxygen levels at the deepest point (36 metres) were restored to 9.1 mg/L. The thermocline developed during the summer '84 and spring '85 surveys at a depth varying from 18 to 28 metres.

The DO isopleth diagram (Figure 32) for Station 5 - Opposite Douglas Provincial Park - indicates that DO levels were fairly uniform for the ice-free period, dropping slightly below the objective of 5.0 mg/L at the bottom during the July 31 and August 28 surveys. During

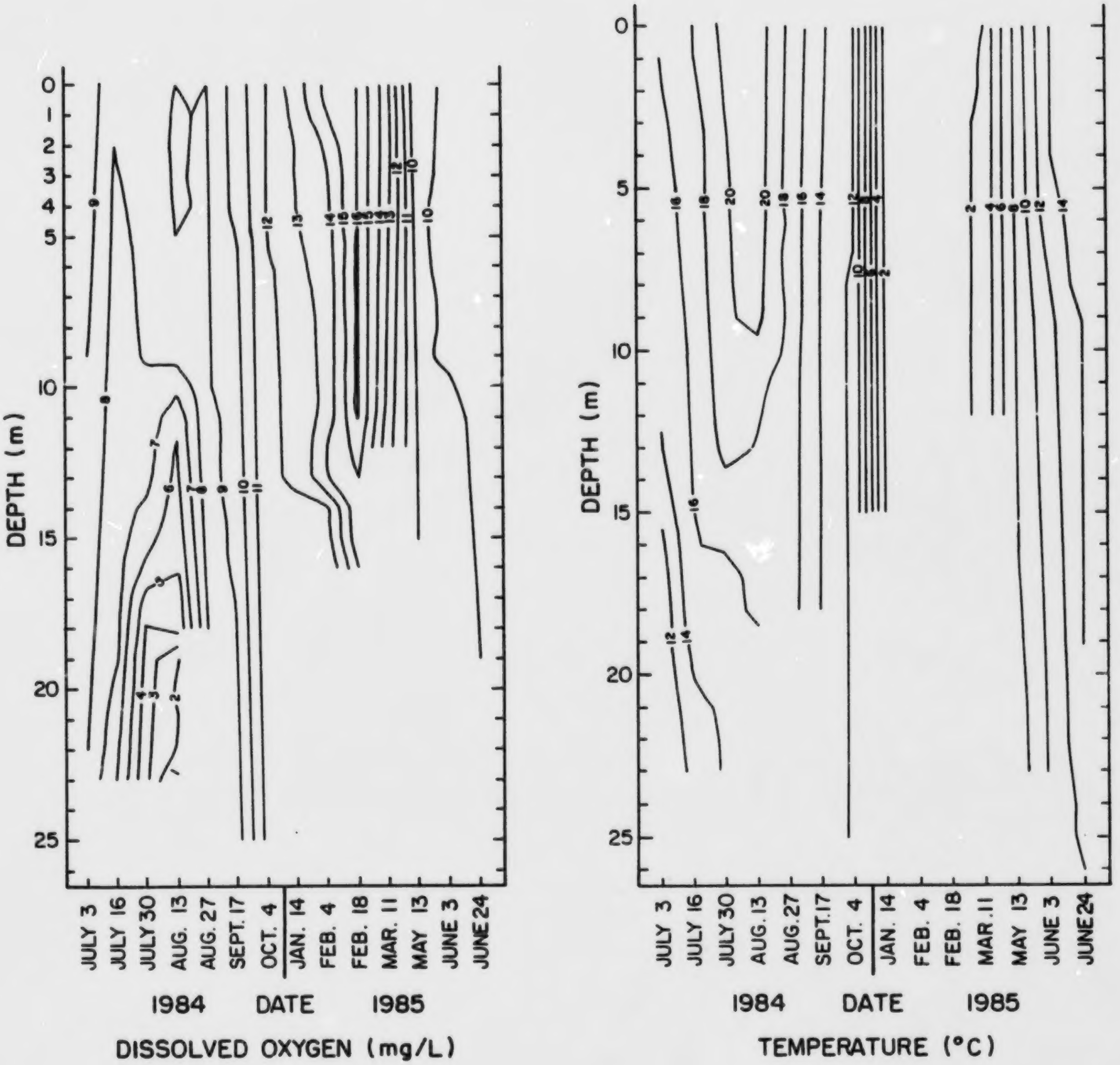
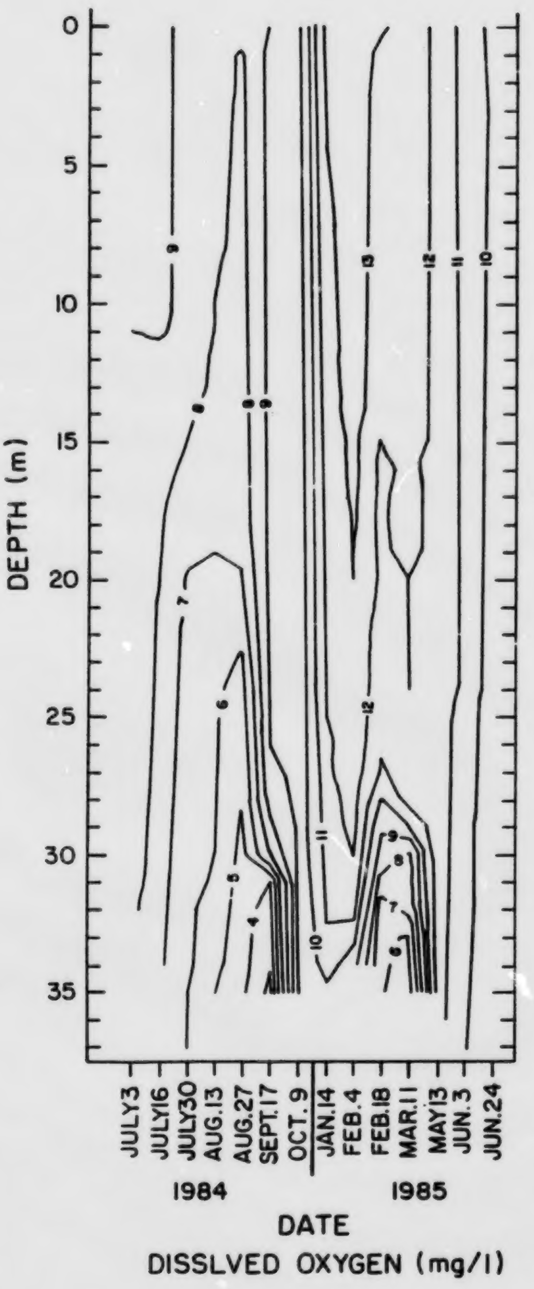


Figure 30 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN (LEFT) AND TEMPERATURE (RIGHT) FOR LAKE DIEFENBAKER STATION 3 , 1984 - 1985



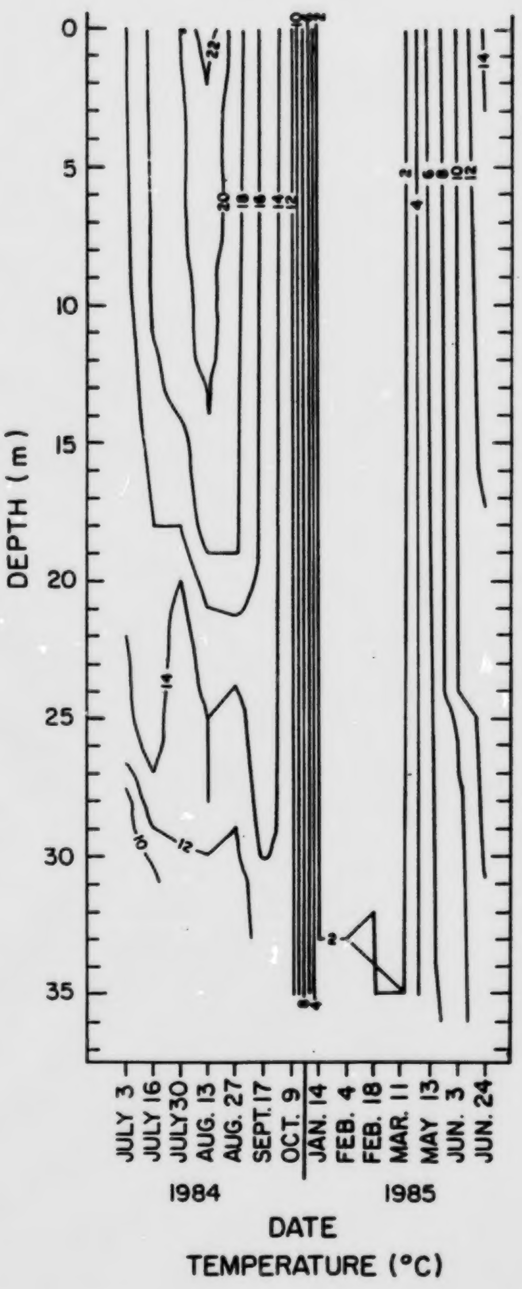


Figure 31 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN (LEFT) AND TEMPERATURE (RIGHT) FOR LAKE DIEFENBAKER STATION 4, 1984 - 85

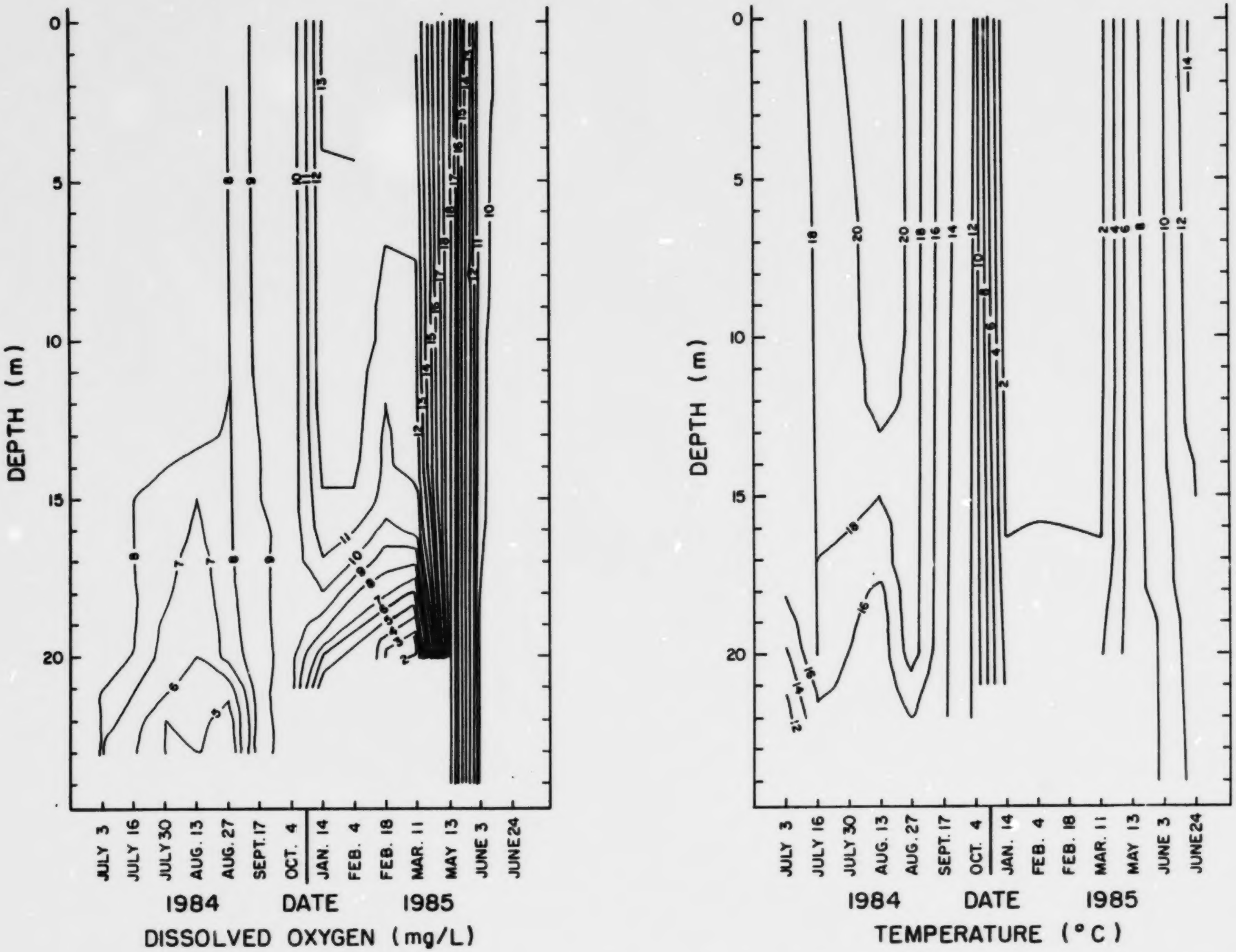
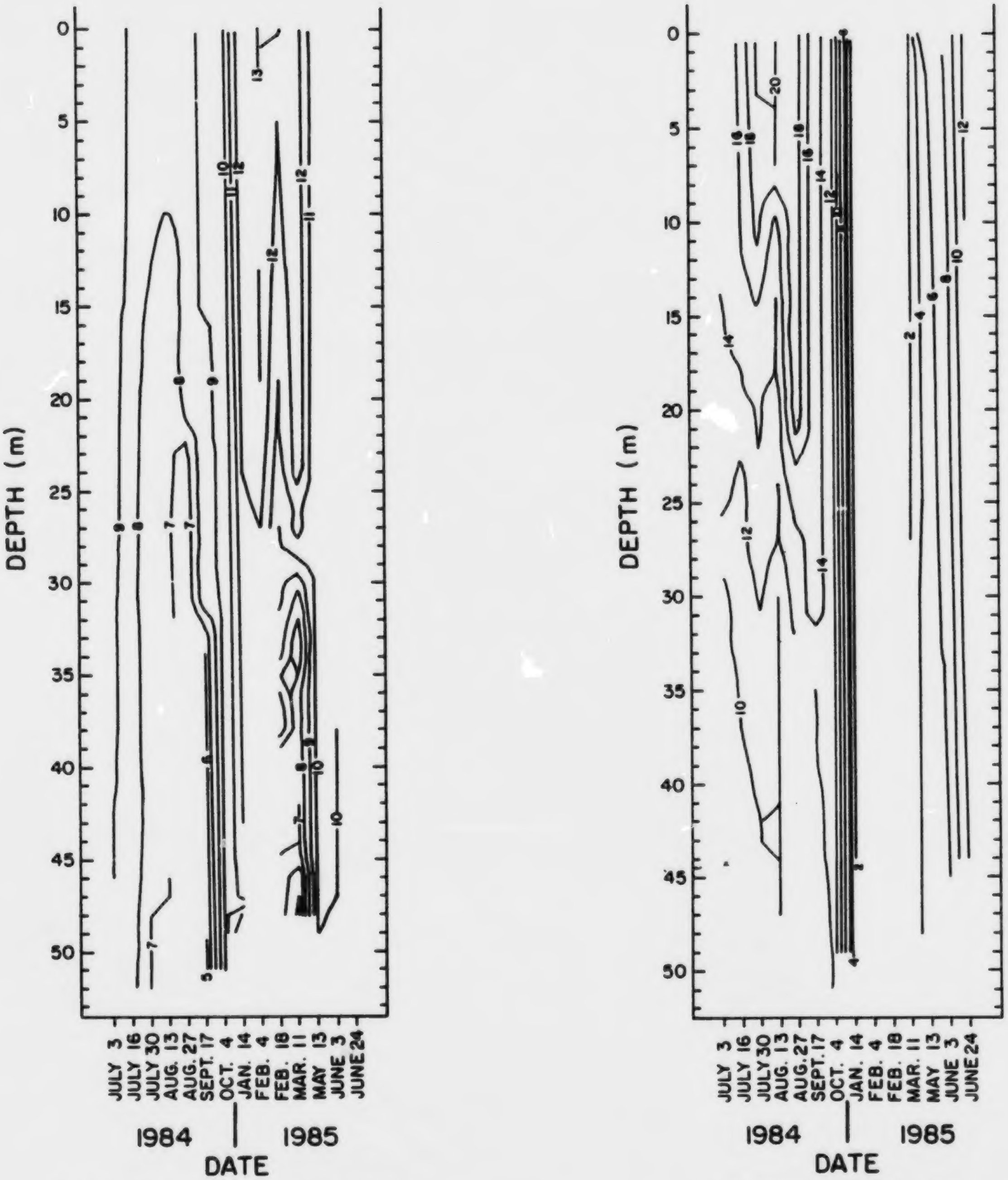


Figure 32 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN (LEFT) AND TEMPERATURE (RIGHT) FOR LAKE DIEFENBAKER STATION 5 , 1984 - 1985

the winter months, however, there was a more significant reduction in DO, especially for the late winter survey conducted on March 11, 1985. Here the oxygen levels dropped to 1.8 mg/L at the bottom. The amount of oxygen consumed in the hypolimnion not only increases with depth but can become increasingly depleted as the winter progresses. The ongoing demands of decomposition, especially at the sediment-water interface, combined with long periods of time with no oxygen replenishment, can reduce the oxygen content to very low levels. This is a fairly typical situation for a lake with moderate productivity.

The DO data (Figure 33) for Station 6 - Opposite Danielson Provincial Park - indicates that DO levels remained satisfactory for all surveys except for decreases during the September 18 and March 11 surveys when DO levels dropped slightly below 5.0 mg/L at the 49-53 metre depth. Historical data indicate that this area of the lake is oligotrophic (low in nutrients) which may explain the uniform DO levels present in spite of the depth encountered. Since there are reduced levels of nutrients present, there is less decomposition of organic matter and hence less reduction of DO at lower depths. Also, the ongoing release of water from Gardiner Dam to the South Saskatchewan River may enhance circulation and help to maintain satisfactory DO levels in that portion of the lake.



DISSOLVED OXYGEN (mg/L)

TEMPERATURE (°C)

Figure 33 : DEPTH - TIME DIAGRAM OF ISOPLETHS OF DISSOLVED OXYGEN (LEFT) AND TEMPERATURE (RIGHT) FOR LAKE DIEFENBAKER STATION 6 , 1984 - 1985

Overall, the isopleth diagrams (formulated from the DO profiles) for Lake Diefenbaker indicate that for the most part DO levels exceeded the Saskatchewan surface water quality objective of 5.0 mg/L. The exceptions to this were some low levels experienced during summer stratification and under ice-covered conditions but these occurred at the deep sample points near the lake bottom. Low DO levels in isolated portions of the lake or near the bottom are not a concern as long as fish and other aquatic organisms can move to areas with more satisfactory levels. Results for Lake Diefenbaker indicated that the oxygen levels quickly recovered during the spring and fall overturns.

4.2.2 Nutrients and Related Parameters

Quality Assurance

The co-operative nature of this study and its dependence on the historical database for providing a water quality perspective required that data from a number of laboratories be compared.

To ensure continuing reliability a seasonal inter-laboratory quality assurance program was implemented over the duration of the field study. Single samples from all six study stations on Lake Diefenbaker were split seven ways and each laboratory analyzed the splits for major nutrient parameters and suspended solids. Table 11 shows

Table 11

Lake Diefenbaker Inter-Lab Quality Assurance Program: Comparison of Provincial Lab Data to Environment Canada Data Using Major Parameters - in mg/L (1984-85)

Sampling Date	Station	Ammonia (NH_3)		Nitrate & Nitrite (NO_3 & NO_2)		Total Phosphorus (TP)		Ortho-Phosphorus (Ortho-P)		Dissolved Organic Carbon (DOC)		Total Suspended Solids (TSS)	
		Env. Can.	Prov. Lab.	Env. Can.	Prov. Lab.	Env. Can.	Prov. Prov.	Env. Can.	Prov. Lab.	Env. Can.	Prov. Lab.	Env. Can.	Prov. Lab.
July 30/84	1	0.1	0.03	0.01	<0.03	0.061	0.05	<0.003	<0.01	2.6	5	22	15
	2	0.020	0.05	0.034	<0.03	0.096	0.06	0.069	<0.01	2.9	4	28	7
	3	<0.1	0.09	0.15	0.14	0.01	0.04	0.004	0.01	2.9	4	5	4
	4	<0.1	0.05	0.07	0.07	0.004	0.02	<0.003	<0.1	2.4	4	<1	2
	5	<0.1	0.05	0.03	0.07	0.003	0.03	<0.003	<0.01	2.4	4	2	3
	6	<0.1	0.05	0.07	0.07	0.004	0.05	<0.003	0.02	2.5	4	2	2
Feb. 4/85	1	0.43	0.45	1.4	1.62	0.042	0.07	0.012	0.03	1.3	–	39	35
	2	0.54	0.56	1.4	1.62	0.028	0.03	0.015	0.03	1.7	–	10	9
	3	0.12	0.12	0.25	0.24	0.01	0.03	<0.003	0.02	2.6	–	3	3
	4	<0.1	0.03	0.06	0.10	0.007	0.04	0.003	0.03	2.7	–	1	2
	5	<0.1	<0.01	0.04	0.07	0.007	0.01	<0.003	<0.01	2.6	–	3	2
	6	<0.1	<0.01	0.04	0.07	0.007	0.02	<0.003	<0.01	2.6	–	1	2
June 24/85	1	<0.05	0.04	<0.01	<0.03	0.024	0.08	<0.003	0.01	2.7	3	8	12
	2	<0.05	0.05	<0.01	<0.03	0.021	0.05	<0.003	0.01	2.4	3	6	11
	3	<0.05	0.04	0.22	0.20	0.017	0.04	<0.003	0.01	3.5	4	6	7
	4	<0.05	0.04	0.17	0.17	0.012	0.04	<0.003	<0.01	2.7	3	–	5
	5	0.12	0.04	0.04	0.03	0.007	0.02	<0.003	<0.01	2.5	3	3	5
	6	<0.05	0.04	0.06	0.07	0.011	0.03	<0.003	0.01	2.6	3	1	4

< = means 'less than'

the results for this program for the two principal labs used during the study - Environment Canada and the Provincial Laboratories. There is a general trend to lower readings reported by the Environment Canada lab.

This is consistent with the observation that Environment Canada was generally able to achieve somewhat lower detection levels for the key nutrient parameters. Subsequently, calculations made for the purpose of defining the trophic status of the lake (Chapter 5) used data from the Environment Canada laboratory.

Replication was done at two sites - Saskatchewan Landing and Riverhurst. At each location during each sampling trip a 30 x 100 metre grid was established and random numbers were used to determine the five collection sites on the grid. Selecting the number of replicates involved a compromise between the amount of effort that was reasonable and the estimated precision of the mean that was acceptable (Tones, 1984).

Table 12 shows the results of replication at Station 2 - Saskatchewan Landing for several sampling dates and selected nutrient parameters. The standard deviations showed that there was little variation among replicates for most parameters. Dissolved organic carbon (DOC) showed some variation on the January 14, 1985 sampling date.

Although replicates indicate precision, they do not measure accuracy. In order to check for contamination in the field or laboratory, high quality distilled water was brought into the field in carefully cleaned containers. When two crews were sampling independently, one blank at the beginning of the trip and one at the end for each crew were considered sufficient.

Table 12

A Comparison of Replicate Samples for
Lake Diefenbaker at Saskatchewan Landing for Selected Parameters
1984-85

			Parameter		
Sampling Date	TP	DP	DN	PN	DOC
July 3/84	.045	<.003	.24	.16	3.1
	.067	<.003	.24	.21	2.5
	.055	<.003	.26	.19	2.5
	.07	<.003	.25	.19	2.4
	.035	<.003	.24	.17	2.4
Mean	.054	<.003	.25	.18	2.6
Stn. Dev.	.015	0	.009	.019	.295
Oct. 9/84	.025	.003	.26	.09	2.4
	.04	.003	.32	.12	2.6
	.039	.013	.32	.14	2.6
	.047	.009	.31	.15	2.7
	.022	.003	.29	.08	2.7
Mean	.035	.006	.30	.12	2.6
Stn. Dev.	.011	.005	.025	.030	.122
Jan. 14/85	.025	.02	1.8	.03	1.3
	.04	.013	1.8	.05	1.2
	.039	.018	1.8	.03	3.7
	.047	.015	1.8	.03	1.1
	.022	.013	1.8	.04	1.4
Mean	.035	.016	1.8	.04	1.7
Stn. Dev.	.011	.003	0	.009	1.101

Analysis of the blank samples showed no contamination present and therefore no adjustments were required in the sampling methods.

Nitrogen

Mean total kjeldahl nitrogen (TKN) concentrations by sampling station for Lake Diefenbaker appear on Table 13. Note that stations 2 and 4 were sampled more frequently and subsequent discussion will often focus on information obtained at these locations.

Table 13

Mean TKN Concentrations for Lake Diefenbaker - in mg/L

	Seasonal Means								Study Period	Hist- orical
	Summer '84		Fall'84		Winter'85		Spring'85			
Station	n	mean	n	mean	n	mean	n	mean	mean	mean
1 - Cabri	1	1.0	-	-	2	0.90	1	1.0	0.95	—
2 - Sask. Landing	10	0.77	5	0.74	20	0.99	15	0.63	0.81	0.64
3 - Herbert	1	1.2	-	-	1	0.3	1	0.8	0.77	—
4 - Riverhurst	10	0.47	5	0.54	20	0.54	15	0.51	0.52	0.52
5 - Douglas	1	0.60	-	-	2	0.35	1	0.70	0.50	0.50
6 - Danielson	2	0.38	-	-	2	0.45	1	0.70	0.53	0.46

n - number of samples

Seasonal means for Station 2 ranged from 0.63 mg/L in spring of 1985 to 0.99 mg/L during the winter of that year. Station 4 showed little seasonal trend with TKN values ranging from 0.47 mg/L to 0.54 mg/L. These findings are similar to those noted in Section 3.2.1 in which dissolved nitrogen concentrations at Lemsford were found to be highly variable throughout the year, with highest concentrations occurring in winter, while results for Gardiner Dam showed much lower variability in dissolved nitrogen.

Historical data are available for 4 sites on Lake Diefenbaker. A review of these data (Table 15) showed that concentrations of TKN, which ranged between 0.46 and 0.64 mg/L were highest in the upper reaches of the lake. This corresponded to the study period findings.

Mean nitrate-nitrite nitrogen (NO_3 - NO_2) concentrations by station are shown in Table 14. NO_3 - NO_2 values were highest during the winter period. Study period mean data showed spatial trends within Lake Diefenbaker, a tendency to decreasing concentrations downstream.

Data for dissolved nitrogen (DN), particulate nitrogen (PN) and total nitrogen (TN) are presented in Figures 34 to 36.

Highest concentrations of DN (Figure 34) were found during the winter period. This was most noteable at the upstream sites, similar to the results obtained for TKN.

Table 14

Mean $NO_3 + NO_2$ Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L

	Seasonal Means								Study
	Summer '84		Fall'84		Winter'85		Spring'85		Period
Station	n	mean	n	mean	n	mean	n	mean	mean
1 - Cabri	5	0.030	2	0.025	4	1.325	6	0.272	0.419
2 - Sask. Landing	31	0.045	10	0.062	20	1.319	16	0.117	0.393
3 - Herbert	7	0.111	2	0.015	4	0.088	6	0.410	0.191
4 - Riverhurst	35	0.073	10	0.054	20	0.133	15	0.103	0.091
5 - Douglas	6	0.035	2	N/A	4	0.058	7	0.050	0.047
6 - Danielson	14	0.064	2	0.070	4	0.105	7	0.090	0.077

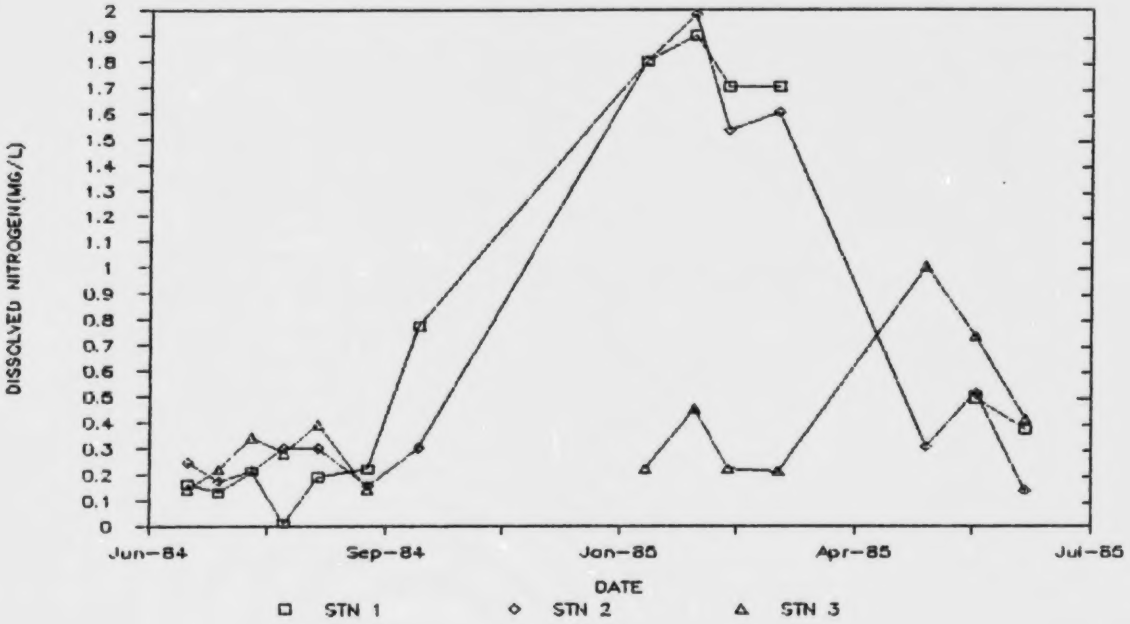
n - number of samples
< - less than
N/A - not available

Figure 35 shows the concentrations of PN present in Lake Diefenbaker during the study period. Results were quite variable at the upstream stations, especially at Station 1. Levels at most stations were lower in the late fall and winter period.

Levels of total nitrogen were also higher at the upstream stations due to the inflow of nutrients via the South Saskatchewan River. A comparison of Figures 34 and 36 indicates that most of the nitrogen present was in the dissolved form.

Phosphorus

Mean total phosphorus (TP) values by station for the Lake Diefenbaker study appear in Table 17.



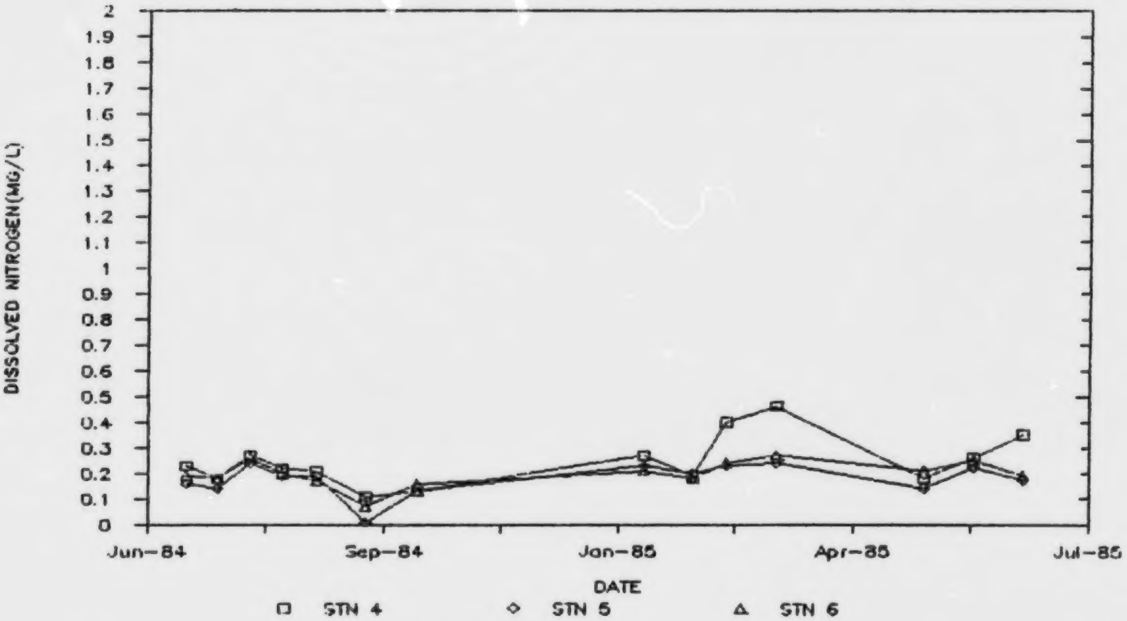


Figure 34 : LAKE DIEFENBAKER STUDY DATA FOR DISSOLVED NITROGEN (MEANS/RUN) - STATIONS 1-3 (TOP) AND STATIONS 4-6 (BOTTOM).

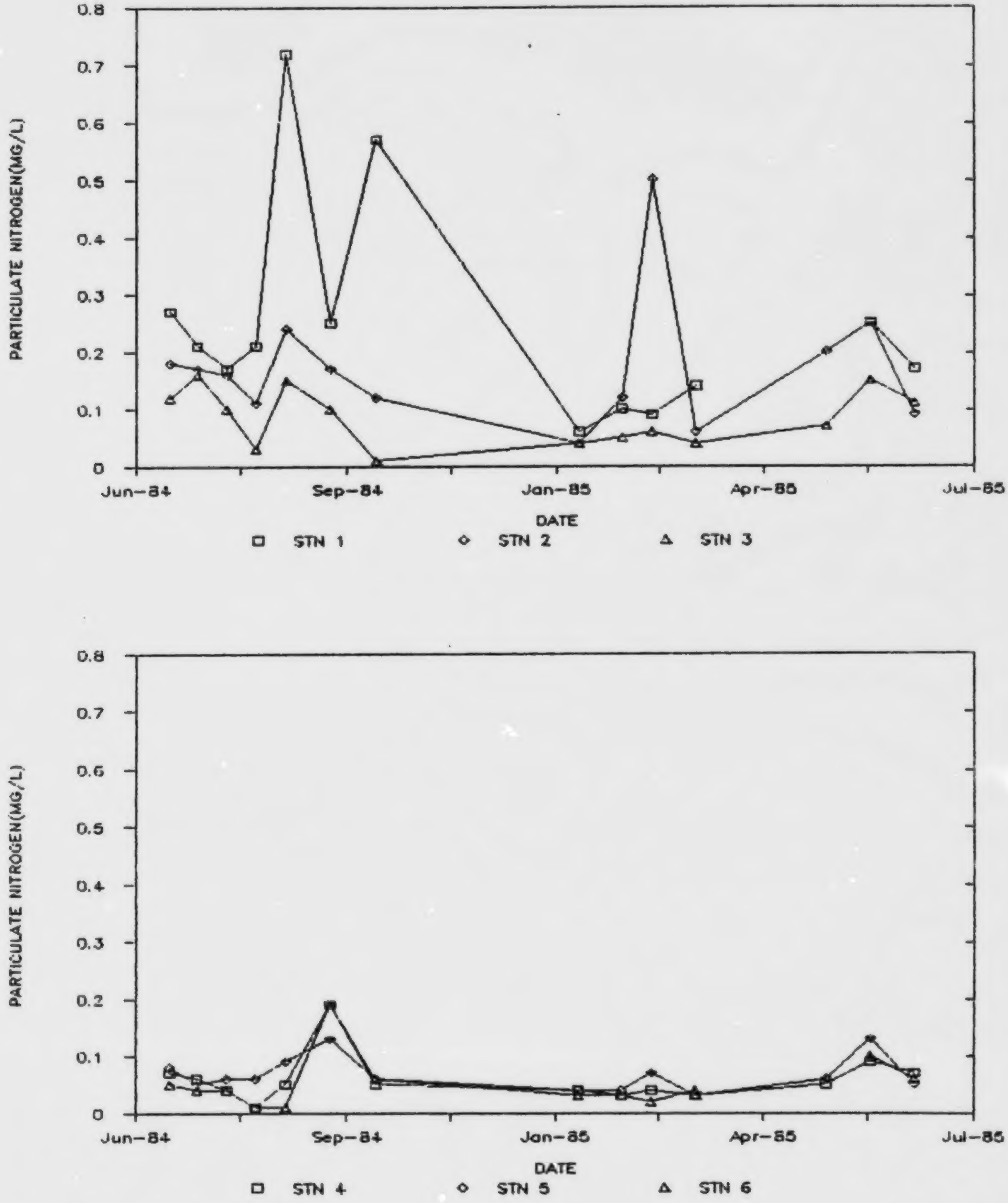


Figure 35 : LAKE DIEFENBAKER STUDY DATA FOR PARTICULATE NITROGEN (MEANS/RUN) - STATIONS 1-3 (TOP) AND STATIONS 4-6 (BOTTOM).

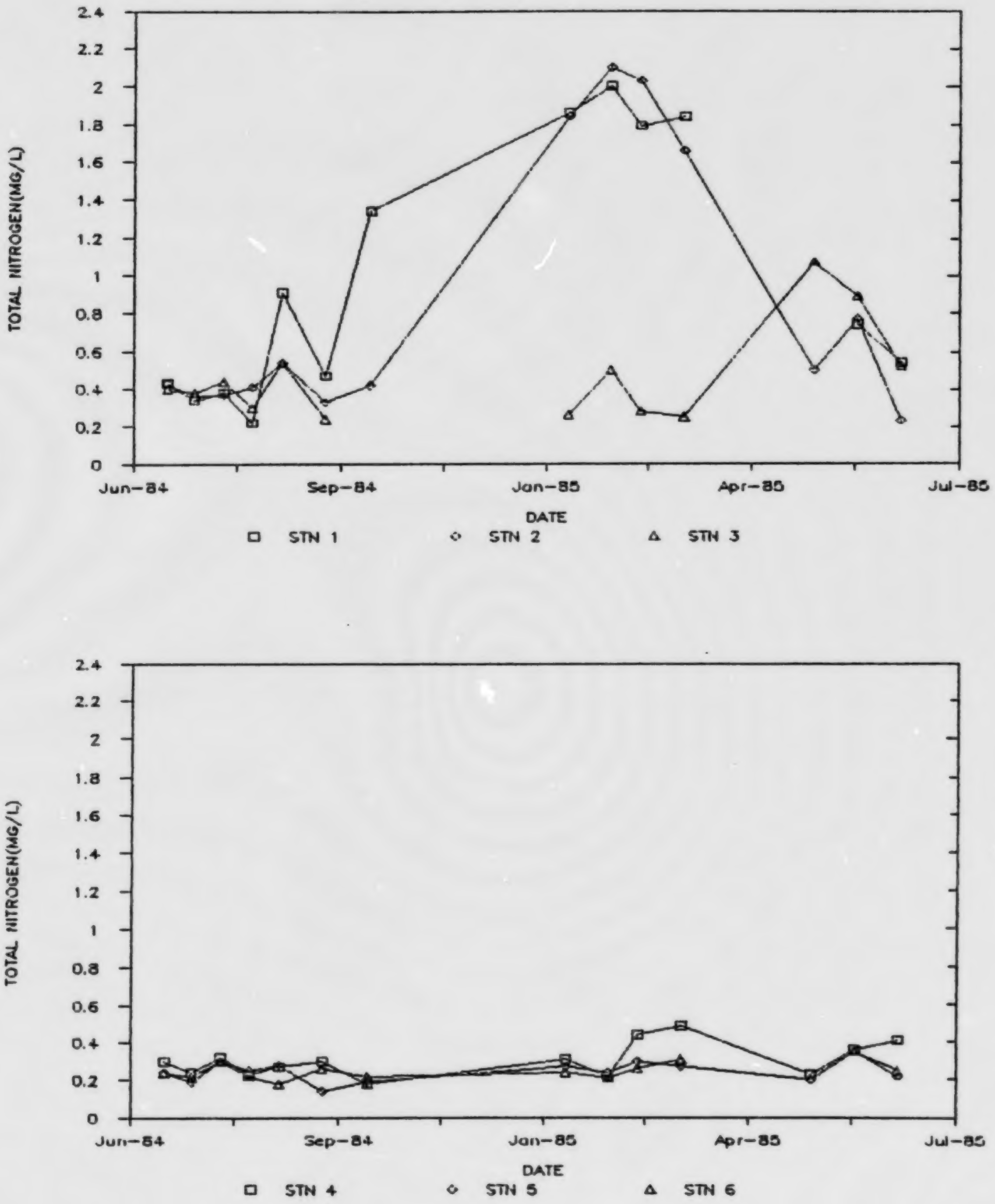


Figure 36 : LAKE DIEFENBAKER STUDY DATA FOR TOTAL NITROGEN (MEANS/RUN) - STATIONS 1-3 (TOP) AND STATIONS 4-6 (BOTTOM).

Table 15

Mean Total Phosphorus Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L

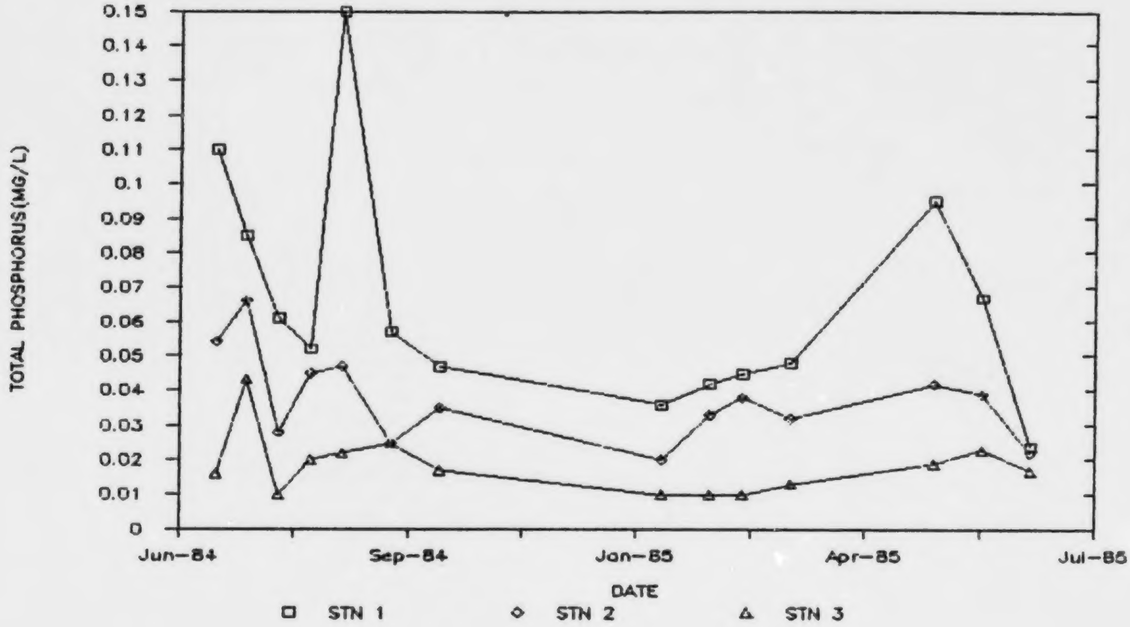
	Seasonal Means								Study Period
	Summer '84		Fall'84		Winter'85		Spring'85		
Station	n	mean	n	mean	n	mean	n	mean	mean
1 - Cabri	5	.092	2	.052	4	.043	7	.065	.066
2 - Sask. Landing	31	.049	10	.030	20	.031	16	.035	.039
3 - Herbert	7	.021	2	.021	4	.011	6	.021	.019
4 - Riverhurst	35	.014	10	.020	20	.011	15	.012	.014
5 - Douglas	6	.024	2	.018	4	.015	7	.019	.020
6 - Danielson	14	.012	2	.011	4	.009	7	.011	.011

n - number of samples

The study period mean TP ranged from 0.011 mg/L to 0.066 mg/L. The latter value, recorded at Station 1, exceeded the Saskatchewan Surface Water Quality objective of 0.05 mg/L. The higher mean TP values observed during the summer of 1984 at Stations 1 and 2 reflect the input of nutrients from the South Saskatchewan River. There was a spatial trend to lower TP values in a downstream direction.

Seasonal mean TP and DP data for the Lake Diefenbaker study period (1984-85) are summarized in Figures 37 and 38.

At the upstream locations - Stations 1 and 2 - increased levels of phosphorus-bearing sediment would normally be



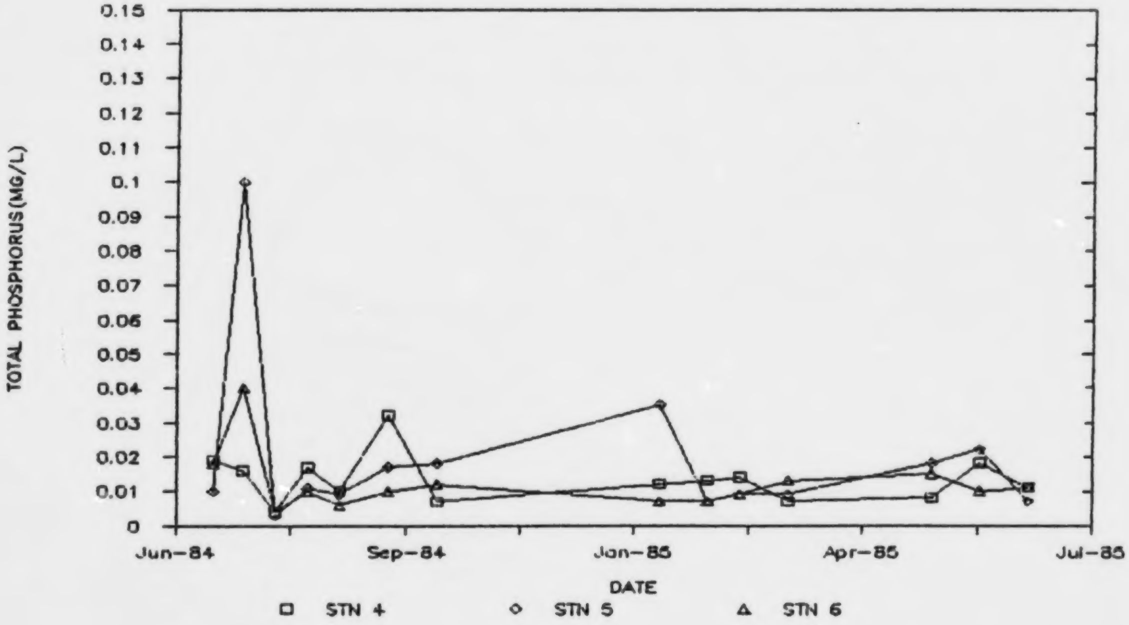
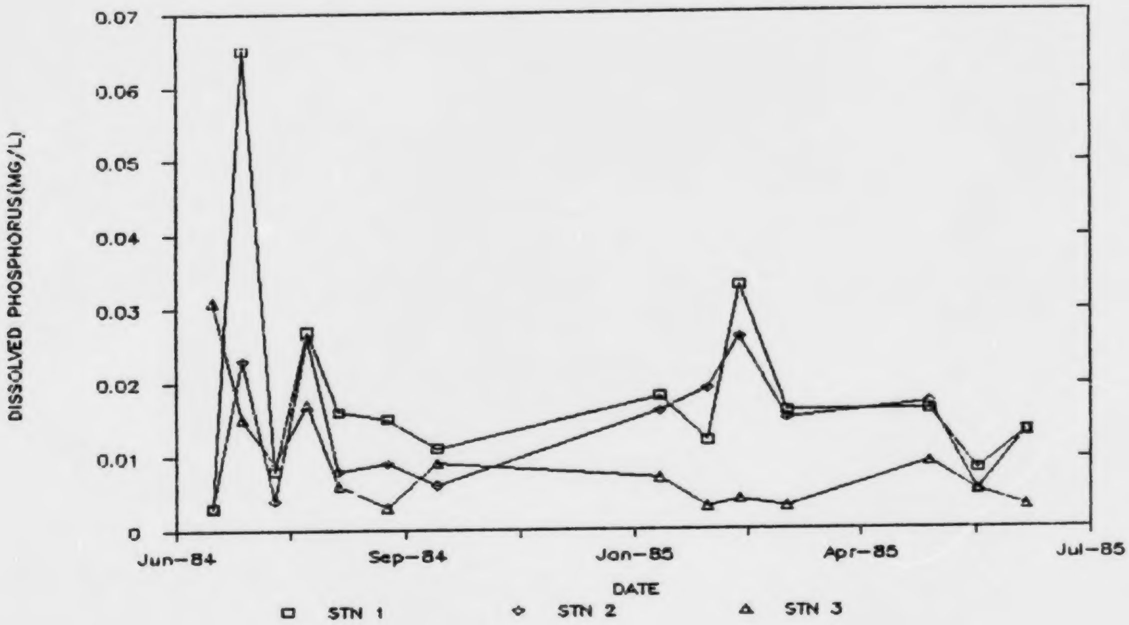


Figure 37 : LAKE DIEFENBAKER STUDY DATA FOR TOTAL PHOSPHORUS (MEANS/RUN) - STATIONS 1-3 (TOP) AND STATIONS 4-6 (BOTTOM).



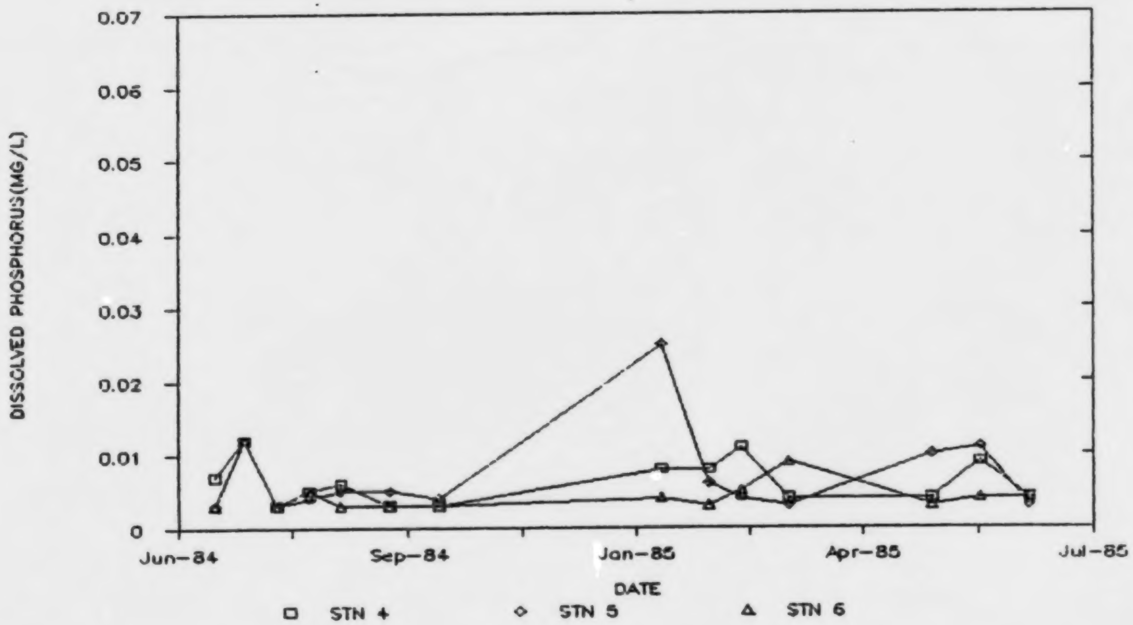


Figure 38 : LAKE DIEFENBAKER STUDY DATA FOR DISSOLVED PHOSPHORUS (MEANS/RUN) - STATIONS 1-3 (TOP) AND STATIONS 4-6 (BOTTOM).

suspended in the water column under the high flow conditions occurring during spring and early summer. Of the TP present in the lake it is expected that about 95 per cent or more is associated with particulate material and the remainder is present as DP. Figure 38 shows the trend for DP during the Lake Diefenbaker study period. Levels of DP remained quite low over the year at all stations except for Stations 1 and 2 which increased significantly during the winter months. In winter, low temperatures and ice cover reduce plant growth and uptake of DP while concurrent decomposition of plant and animal debris from the previous growing season release additional DP to the water column. Also, during the fall and winter, biologically available forms of phosphorus are transported more directly into Lake Diefenbaker since there would be reduced uptake by aquatic plants and algae in the river upstream.

Carbon

Mean dissolved organic carbon (DOC) concentrations by station for the Lake Diefenbaker study period are summarized on Table 16.

Study period mean concentrations ranged from 2.3 mg/L to 2.7 mg/L, on the low side of the environmental range of 1 to 30 mg/L reported for natural surface waters by McNeely

Table 16

Mean DOC Concentrations for the Lake Diefenbaker Study (1984-85) - in mg/L

	Seasonal Means								Study Period
	Summer '84		Fall'84		Winter'85		Spring'85		
Station	n	mean	n	mean	n	mean	n	mean	mean
1 - Cabri	5	2.0	2	4.6	4	1.6	7	2.4	2.4
2 - Sask. Landing	31	2.7	10	2.4	20	1.5	16	3.2	2.5
3 - Herbert	7	2.4	2	2.2	4	2.5	6	3.3	2.7
4 - Riverhurst	35	2.5	10	1.3	20	2.5	15	2.6	2.4
5 - Douglas	6	2.6	2	1.2	4	2.1	7	2.5	2.3
6 - Danielson	14	2.4	2	1.2	4	2.5	7	2.5	2.4

n - number of samples

et al., (1979). There was some variation seasonally especially at Stations 1-3. During the period of a year a lake normally experiences dramatic metabolic changes. Significant spatial trends were apparent during the fall sampling period, with decreasing concentration downstream through the lake.

Chlorophyll "a"

Mean chlorophyll "a" concentrations for the Lake Diefenbaker study are shown by station in Table 17.

Study period mean chlorophyll "a" concentrations ranged from 2 to 6 ug/L (micrograms per litre). The apparent trend for decreasing chlorophyll "a" concentrations in a downstream direction is evident on an annual as well as a seasonal basis.

Table 17

Mean Chlorophyll "a" Concentrations for the Lake Diefenbaker Study (1984-85) - in ug/L

	Seasonal Means								Study Period
	Summer '84		Fall'84		Winter'85		Spring'85		
Station	n	mean	n	mean	n	mean	n	mean	mean
1 - Cabri	5	5	2	8	4	1	6	4	4
2 - Sask. Landing	31	6	10	7	20	1	15	12	6
3 - Herbert	6	3	2	7	4	4	7	6	5
4 - Riverhurst	35	2	9	1	20	1	15	5	2
5 - Douglas	6	1	2	1	3	<1	7	3	2
6 - Danielson	14	<1	2	1	4	1	7	3	2

n - number of samples
< - less than

Seasonal peak concentrations occurred in late summer and early fall, 1984 at Station 1, while at Stations 2 through 6 the peak levels were experienced in late spring, 1985. The lowest mean seasonal chlorophyll "a" levels at all stations except Station 3 were measured during the ice covered conditions of winter, 1985. Mean chlorophyll "a" levels at Station 3 increased from 1.0 ug/L on October 9, 1984, to 5.0 ug/L in February, 1985. the low chlorophyll "a" concentrations observed during winter, 1985 at the other stations is consistent with reduced algal biovolume during the same period.

In reviewing the chlorophyll "a" data for Lake Diefenbaker it should be noted that the samples obtained were composite samples over the entire water depth. This presents some problems in comparing the data with other available results. The Lake Diefenbaker data are biased low relative to other data obtained from surface samples.

Secchi Depth

Seasonal mean secchi depth (SD) data for each station for the Lake Diefenbaker study are presented in Table 18. There is an obvious trend to higher Secchi depths in a downstream direction. For example, Station 1 recorded a mean summer SD of only 0.32 metres, while at Station 3 the measurement was 2.85 metres and Station 6 was 3.53 metres. The low transparency at the upstream locations (Stations 1 and 2) reflects the effects of more turbid water flowing into the lake from the South Saskatchewan River. Algal productivity was not responsible for the high turbidity since mean biomass was lowest at Stations 1 and 2 respectively (refer to Section 6.1). There was no significant correlation between SD and algal biovolume ($r = -0.121$).

Figure 39 illustrates the annual variations in the Secchi depth at one station on Lake Diefenbaker. Station 4 was chosen for this example because it showed the most variation over the 1984-85 sampling period. Seasonal variations such as those depicted in Figure 39 are common for moderately productive lakes of the temperate zone.

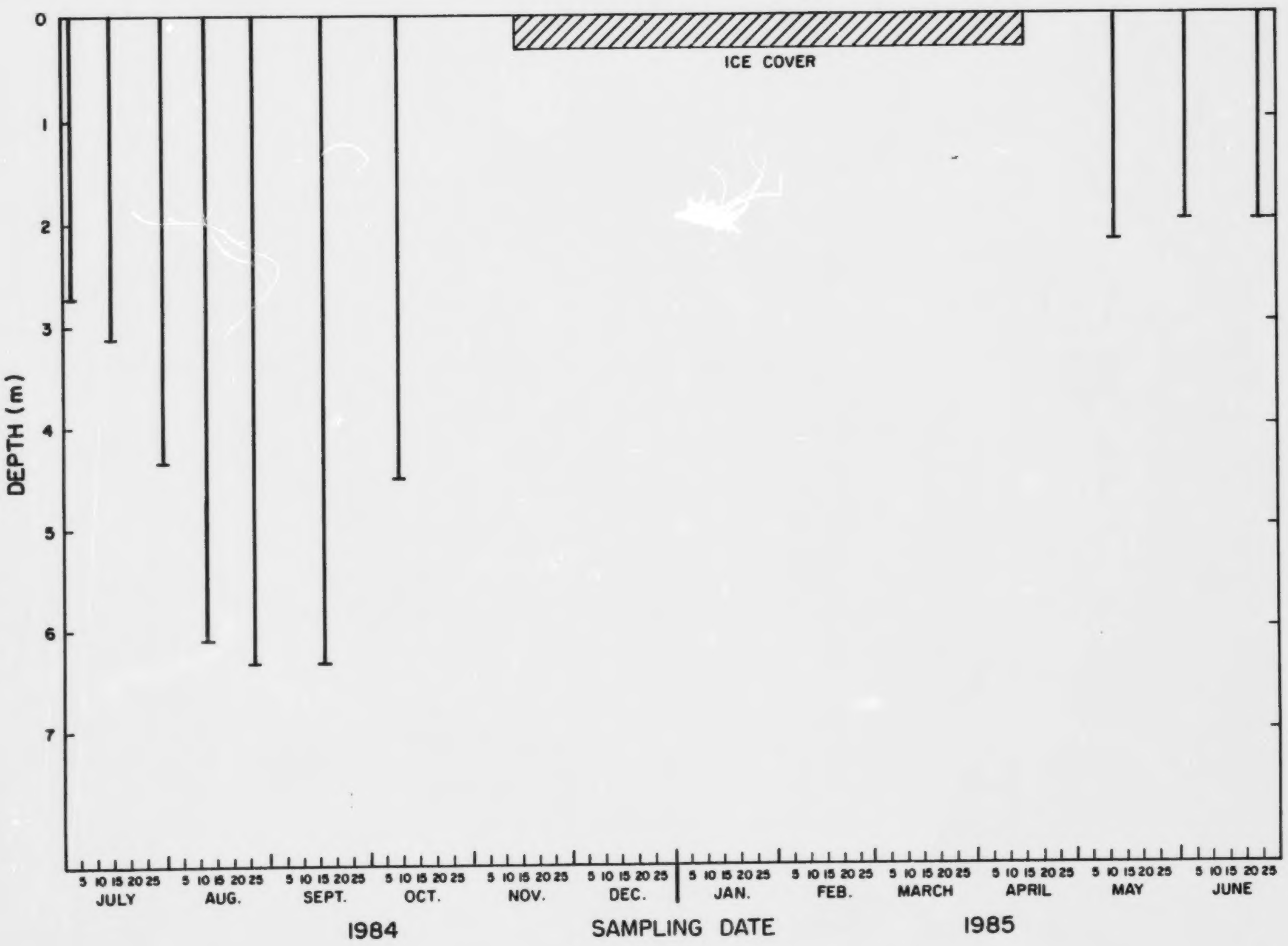


Figure 39 : SEASONAL VARIATIONS IN SECCHI DEPTHS FOR LAKE DIEFENBAKER AT STATION 4 1984 - 1985

Table 18

Mean Secchi Depths for the
Lake Diefenbaker Study (1985-85) - in metres

	Seasonal Means							
	Summer '84		Fall'84		Winter'85		Spring'85	
Station	n	mean	n	mean	n	mean	n	mean
1 - Cabri	5	.32	2	.35	-	-	7	.33
2 - Saskatchewan Landing	36	.72	10	.75	-	-	11	.85
3 - Herbert	6	2.85	2	2.60	-	-	7	1.24
4 - Riverhurst	40	4.15	10	5.40	-	-	15	2.07
5 - Douglas	6	3.30	2	3.05	-	-	7	2.00
6 - Danielson	19	3.53	2	4.70	-	-	9	2.58

n - number of samples

4.2.3 Major Ions and Physical Parameters

Table 19 presents a summary of study period results for the Lake Diefenbaker monitoring stations. Saskatchewan Landing (L2) and Riverhurst Ferry (L4) were the only stations sampled for all major ions during the study period.

The order of predominance of ions during the study was as follows (mean concentration in milliequivalents per litre are noted):

Cations:

L2 Ca (2.33) > Mg (1.40) > Na (0.94) > K (0.09) Total 4.76 meq/L

L4 Ca (2.30) > Mg (1.43) > Na (0.98) > K (0.10) Total 4.81 meq/L

Anions:

L2 HCO_3 (3.03) > SO_4 (1.40) > Cl (0.19) Total 4.62 meq/L

L4 HCO_3 (3.06) > SO_4 (1.42) > Cl (0.17) Total 4.65 meq/L

Little difference in the median concentration of most ions was apparent between these stations or between the lake stations and river stations. As noted in Section 3.2.3 the variation in major ion concentrations decreases downstream through Lake Diefenbaker. The concentration range measured at Saskatchewan Landing was generally three times the range measured at Riverhurst Ferry for most parameters. None of the maximum concentrations for the period of record exceeded the most sensitive use water quality objectives and guidelines (see Table 8).

Table 19

Mean, Maximum and Minimum Concentrations of Physical Parameters and Major Ions, Lake Diefenbaker Stations, 1984-85

	Cabri Park	Sask. Landing	Herbert Ferry	Riverhurst Ferry	Douglas Park	Danielson Park
Number of Samples	14	16	14	17	17	17
pH (mean) pH units	8.2	8.1	8.2	8.2	8.2	8.1
(max)	8.6	8.5	8.5	8.4	8.5	8.4
(min)	7.6	7.7	8.0	7.8	7.6	7.7
Spec Cond (mean) uS/cm	419.	425.	424.	427.	419.	426.
(max)	568.	585.	453.	479.	450.	480.
(min)	292.	314.	397.	387.	360.	368.
Calcium (mean) mg/L		46.8		46.1		
(max)		74.0		54.0		
(min)		36.0		42.0		
Magnesium (mean) mg/L		17.0		17.4		
(max)		22.0		21.0		
(min)		10.0		14.0		
Potassium (mean) mg/L		3.7		3.9		
(max)		6.0		5.0		
(min)		2.0		3.0		
Sodium (mean) mg/L		21.6		22.5		
(max)		40.0		26.0		
(min)		9.0		18.0		
Chloride (mean) mg/L		6.9		5.9		
(max)		14.0		8.0		
(min)		2.0		4.0		
Sulphate (mean) mg/L		67.1		68.2		
(max)		92.0		80.0		
(min)		45.0		48.0		
T.Hardness (mean) mg/L		187.		187.		
(max)		280.		216.		
(min)		136.		172.		
Alkalinity (mean) mg/L	149.	152.	152.	153.	155.	152.
(max)	208.	216.	189.	172.	164.	164.
(min)	110.	114.	132.	142.	146.	142.

(1) On the majority of occasions, a number of point specific samples were taken from different depths in the vertical. The median concentrations from the verticals were used in the preparation of this table.

5. EUTROPHICATION

5.1 Assessment Methodology

Eutrophication is the response of aquatic ecosystems to enrichment by nutrients, particularly phosphorus and nitrogen. The increase in fertility in affected lakes, reservoirs, slow-flowing waters and certain coastal waters causes such symptoms as algal blooms, heavy growths of certain rooted aquatic plants, deoxygenation and, in some cases, unpleasant taste and odour of the water. These problems can impair aesthetic qualities of the water and often result in adverse effects on other water users such as municipalities (water supplies), fisheries and recreational users.

Lakes can be classified biologically on the basis of their productivity. Oligotrophic lakes (meaning low in nutrients) support relatively low levels of productivity. These lakes tend to be deep, clear, and have high concentrations of dissolved oxygen. By contrast, eutrophic lakes are highly productive because they have abundant nutrient supplies. As a result of this and other factors, dense growths of planktonic green and blue-green algae occur in surface waters. Naturally eutrophic lakes tend to be shallow with low transparencies and the dissolved oxygen concentrations may become depleted in the bottom waters during periods of restricted circulation.

Mesotrophic lakes occupy an intermediate position between the two extremes. They are usually intermediate in respect to nutrient supply, depth, biological productivity, water clarity, and oxygen depletion.

In a given climatic zone, lakes in areas of nutrient-rich soil are generally more productive than lakes of similar shape and size in areas of igneous rock drainage (Dillon and Kirchner, 1975). In areas of nutrient-rich soils lakes can become eutrophic due to the constant inflow of nutrients from ground and surface runoff waters. In contrast to this slow process, the phenomenon of cultural or man-made eutrophication is much more rapid, and is caused by enrichment of water with nutrients derived from human activities. The primary sources are municipal sewage disposal and erosion and runoff from farmland and livestock operations.

Eutrophication has been identified as the most significant water quality-related problem in the South Saskatchewan River Basin. Many water bodies in the area are now eutrophic due to both natural and man-made influences.

Increased use of the South Saskatchewan River system by Alberta and Saskatchewan can be expected to accelerate the transport of nutrients into Lake Diefenbaker; this may result in accelerated eutrophication of these waters. This section of the report will examine the current status of our knowledge on the trophic state of the lake and examine the relationships between nutrients and eutrophication.

5.1.1 Nutrient Limitations to Plant Growth

As early as 1840, it was recognized that the growth of plants was limited by the nutrients that were available in the minimal quantity, relative to the plants' needs for growth and reproduction. This formed the basis for the law in plant nutrition which is known as Liebig's Law (Odum, 1971).

The stoichiometry of the phytosynthetic reaction (carbon, nitrogen and phosphorus) is the ratio of 106C: 16N:1P (atomic balance). If this is converted to the mass balance, the ratio of nitrogen to phosphorus is 7.2 :1. There has been an extensive amount of research on this topic in an attempt to determine the critical ratio between these two elements for algae growth. The general conclusion has been that at available N:P ratios of from 5:1 to 10:1 either of the nutrients could be limiting. At N:P ratios over 10:1, phosphorus is the limiting nutrient and at ratios under 5:1, nitrogen is the limiting nutrient (Rast and Lee, 1978).

The OECD work on eutrophication has supported this conclusion (Ryding, 1980; Janus and Vollenweider, 1981; and OECD, 1982). In addition, the OECD (1982) concluded that:

> "...considering all that has been said previously, it can be concluded that in the majority of the cases studied in the OECD program, the production level of these lakes is controlled by phosphorus, not by nitrogen."

In examining modeling of the phosphorus and chlorophyll relationships on Lake Ontario, Scavia and Chapra (1977) concluded that for N:P ratios greater than 12, phosphorus and light are the limiting factors. For N:P ratios of less than 12 nitrogen gains importance and at very low N:P ratios phosphorus no longer has any major control on algal growth. Similar findings were reported for prairie saline lakes by Bierhuizen and Prepas (1985).

Lake Diefenbaker N:P Ratios

Following the suggestion of Rast and Lee (1978) the inorganic nitrogen/ortho-phosphate ratios were calculated for the five study areas of the lake on the fourteen collection dates. The results are summarized in Table 20 and presented graphically for Saskatchewan Landing, Riverhurst and Danielson in Figure 40.

Table 20 shows that the minimum N:P ratio (23) occurred on September 17, 1984 at Riverhurst and that the maximum (475) occurred on February 18, 1985 at Saskatchewan Landing. In comparison to the optimum ratios that were reported in the literature for algal growth the ratios from Lake Diefenbaker are high. This would indicate that the growth of algae in the lake is phosphorus limited (i.e. an increase in the lake concentration of phosphorus will cause a proportional increase in the algal productivity).

Table 20

The Inorganic Nitrogen/Ortho-phosphate Ratios
for the Lake Diefenbaker Mid-Lake Sampling Stations, 1984-85

	July 3 1984	July 16 1984	July 30 1984	Aug 13 1984	Aug 27 1984	Sept 17 1984	Oct 9 1984
Sask. Landing	83	49	60	43	100	53	100
Herbert	93	73	85	93	130	46	NA
Riverhurst	76	36	90	73	70	36	43
Douglas	53	47	80	63	63	43	43
Danielson	63	60	87	67	57	23	53

	Jan 14 1985	Feb 4 1985	Feb 18 1985	Mar 11 1985	May 13 1985	June 3 1985	June 24 1985
Sask. Landing	225	200	475	160	103	157	47
Herbert	73	150	73	70	333	243	137
Riverhurst	67	47	66	115	60	86	116
Douglas	29	66	77	80	47	73	57
Danielson	70	60	80	67	70	83	63

NA - not available

Figure 40 shows that even though there are variations in the ratio within areas of the lake over the year, the entire lake shows a high ratio in comparison to the optimum ratios (10-12) reported in the literature. This indicated that even though the level of phosphorus deficiency varies, the entire lake should respond in a similar manner to changes in the phosphorus loadings.

It is concluded that no further research is necessary to confirm the dependence of algal productivity in Lake Diefenbaker on phosphorus concentration.

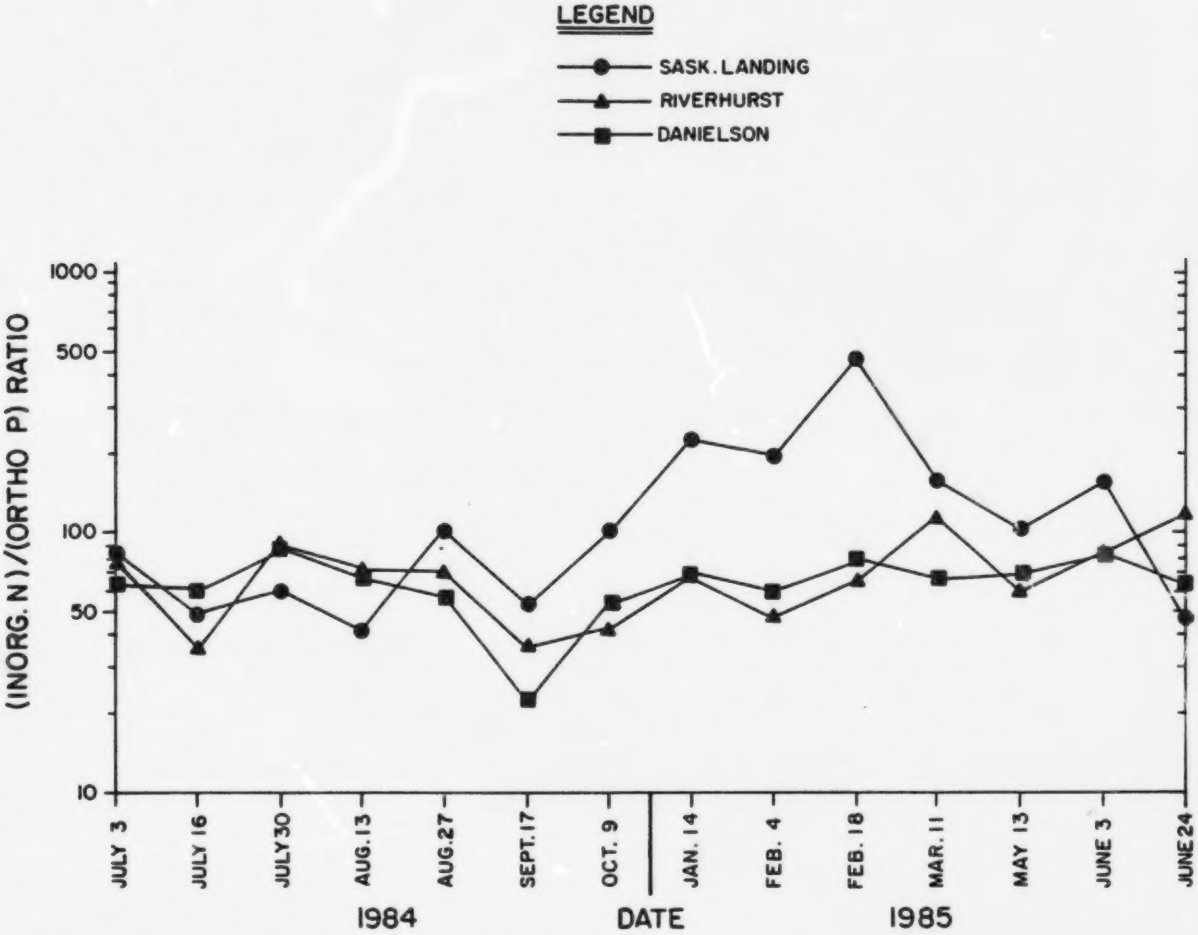


Figure 40 : THE INORGANIC (N) / ORTHO (P) RATIOS FOR THE STUDY PERIOD AT SASKATCHEWAN LANDING , RIVERHURST AND DANIELSON .

5.1.2 Model for Eutrophication Indicator Predictions

Data Considerations

The data on which lake eutrophication models are based in the OECD (1982) analysis contain the yearly loadings of phosphorus to a lake. Yearly phosphorus input to Lake Diefenbaker for the study and historical periods are contained in Section 3.2.2. Looking at Table 5 one finds that the calculated phosphorus loading for 1984 was 247 tonnes and for 1985 was 848 tonnes. The large differences between the loadings in the two years of the study have led to the need to separate the data into two groups. The first group of data will be from July, 1984 to January, 1985, and the second from January, 1985 to June, 1985. The model developed in the following section will be based on the 1984 data.

The length and shape of the lake and the consideration of only the "river input" loadings resulted in splitting the lake into five sections for the purpose of the model. Each of the five sections represents an environmentally distinct area of the lake and can be dealt with separately in the model. These areas will be useful for the future evaluation of regional developments in the five areas. The physical characteristics of these areas are summarized in Table 21.

Table 21

Summary of Physical Characteristics of Lake Diefenbaker Showing the Five Lake Areas and the Whole Lake, 1984-85

	Volume (m^3)	Area (m^2)*	Mean Depth (m)*	Inflow (m^3/y)
Whole Lake	8.97×10^9	4.16×10^8	21.6	3.62×10^9
Sask. Landing	3.73×10^8	3.85×10^7	9.7	3.62×10^9
Herbert	1.77×10^9	1.02×10^8	17.4	3.60×10^9
Riverhurst	2.43×10^9	1.60×10^8	15.2	3.54×10^9
Douglas	1.50×10^9	4.48×10^7	33.4	1.27×10^8
Danielson	2.90×10^9	7.06×10^7	41.1	3.32×10^9

* provided by T. Yuzyk, Water Resources Branch, Environment Canada, Ottawa.

Considering only the river load of phosphorus will tend to underestimate the total phosphorus loading to the lake. It can be assumed that the loadings from other sources to the lake for a one year period will be relatively consistent so that the bias introduced by omitting this data would be consistent and proportional in all five areas of the lake. Further refinement of this model should consider the loadings from all sources.

Modeling Approach

On the advice of Dr. Walter Rast of the United States Geological Survey (USGS), Water Research Division, the OECD (1982) approach was taken in the trophic model for Lake Diefenbaker. It was summarized in the report as follows:

> "Central to the OECD Co-operative Program on Eutrophication is the concept that accelerated eutrophication is caused by excessive nutrient load (externally and internally), and that there exists a quantifiable relationship between nutrient load and trophic reaction of the affected body(ies) of water..."

Figures 41 to 43 present the data in Table 38 graphically and compare them to the OECD (1982) relationships and their 95% confidence limits. These figures demonstrate that for mean summer phosphorus and mean summer chlorophyll "a" values for the five lake area of this study fall within the 95% confidence limits of the OECD model and that this approach to modelling should fit Lake Diefenbaker.

The terminology used in this section and the basis for the relationships developed are outlined or defined in OECD (1982). In cases where the analysis varies from this approach the reasons for the variation are noted.

Data Relationships

The following is a list of the terms and symbols used in this section with definitions:

A = lake area or lake section area (m^3)

V = lake volume or lake section volume (m^3)

Z = mean depth (m)

Q = annual lake inflow or section inflow

Tw = water residence time, V/Q (years)

qs = hydraulic loading, $z/\sqrt{Tw}$ (m/y)

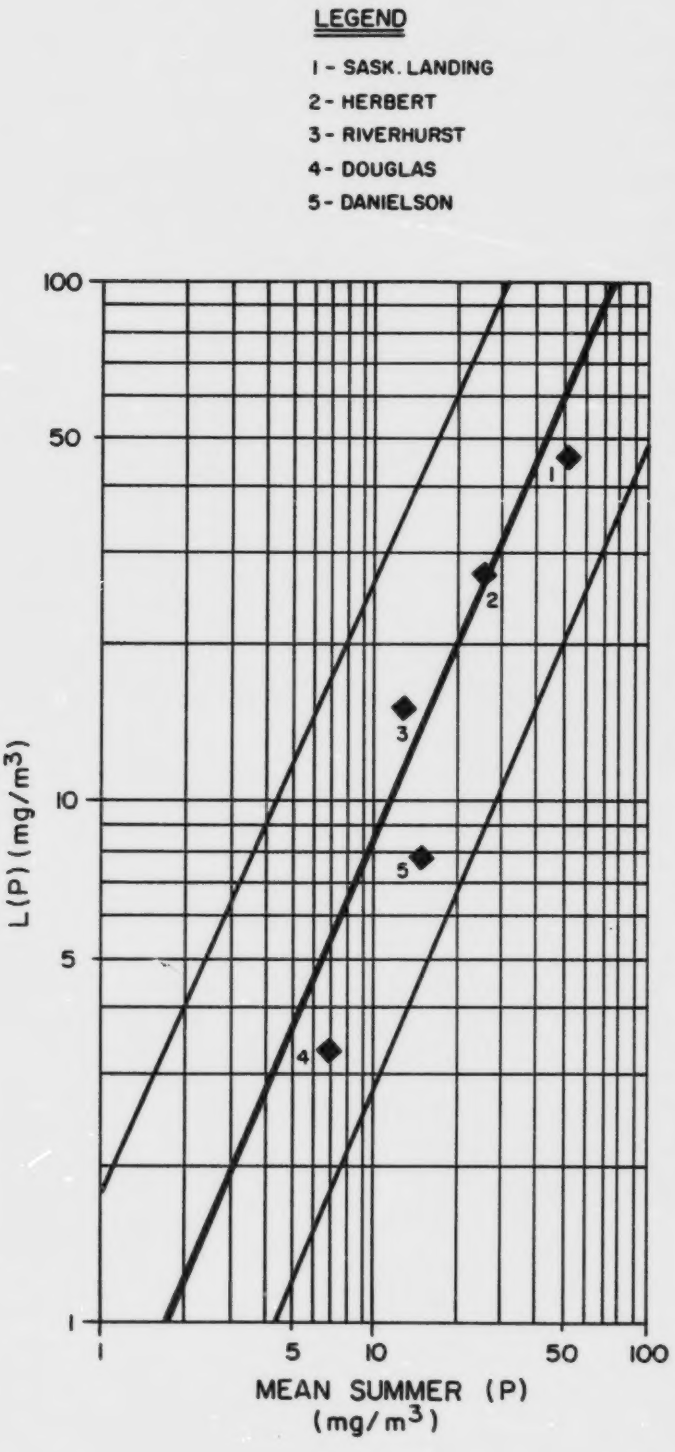


Figure 41: THE MEAN SUMMER PHOSPHORUS CONCENTRATIONS FOR THE FIVE LAKE AREAS COMPARED TO THE OECD (1982) MODEL AND ITS 95 % CONFIDENCE LIMITS.

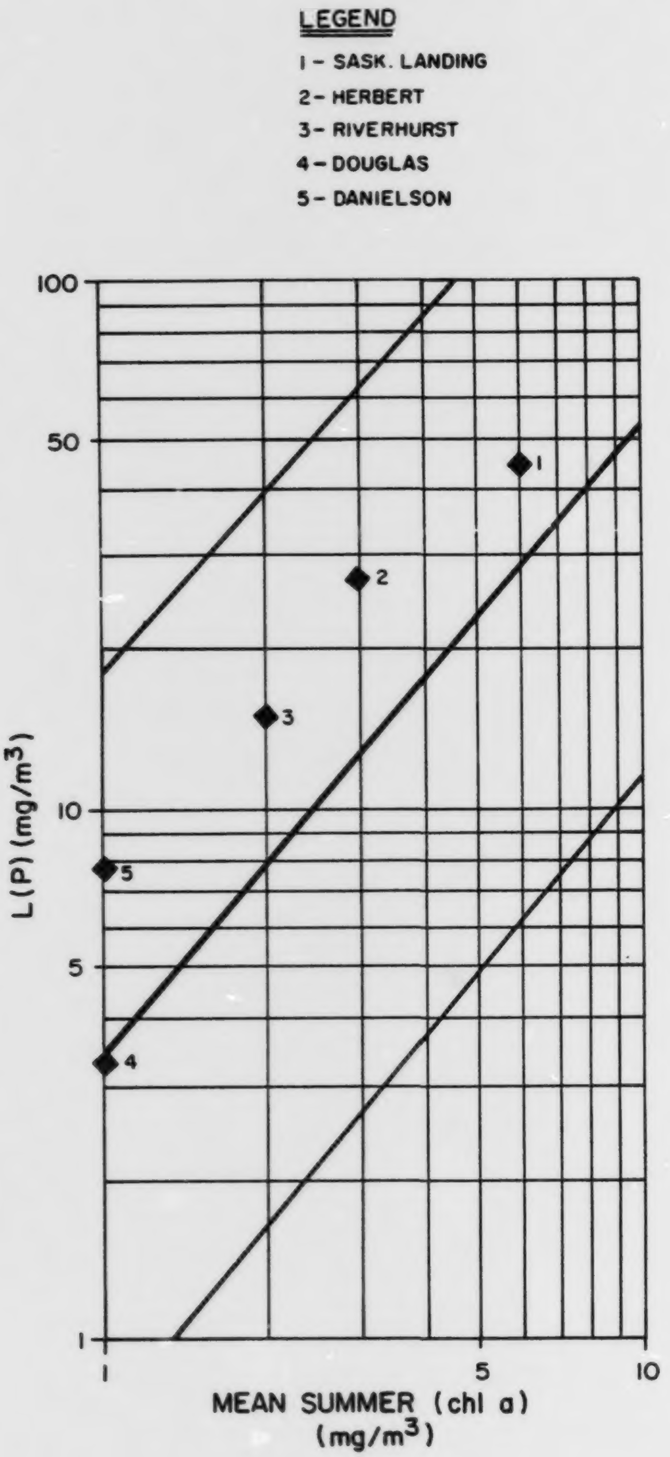


Figure 42 : THE MEAN SUMMER CHLOROPHYLL "a" CONCENTRATIONS FOR THE FIVE LAKE AREAS COMPARED TO THE OECD (1982) MODEL AND ITS 95 % CONFIDENCE LIMITS.

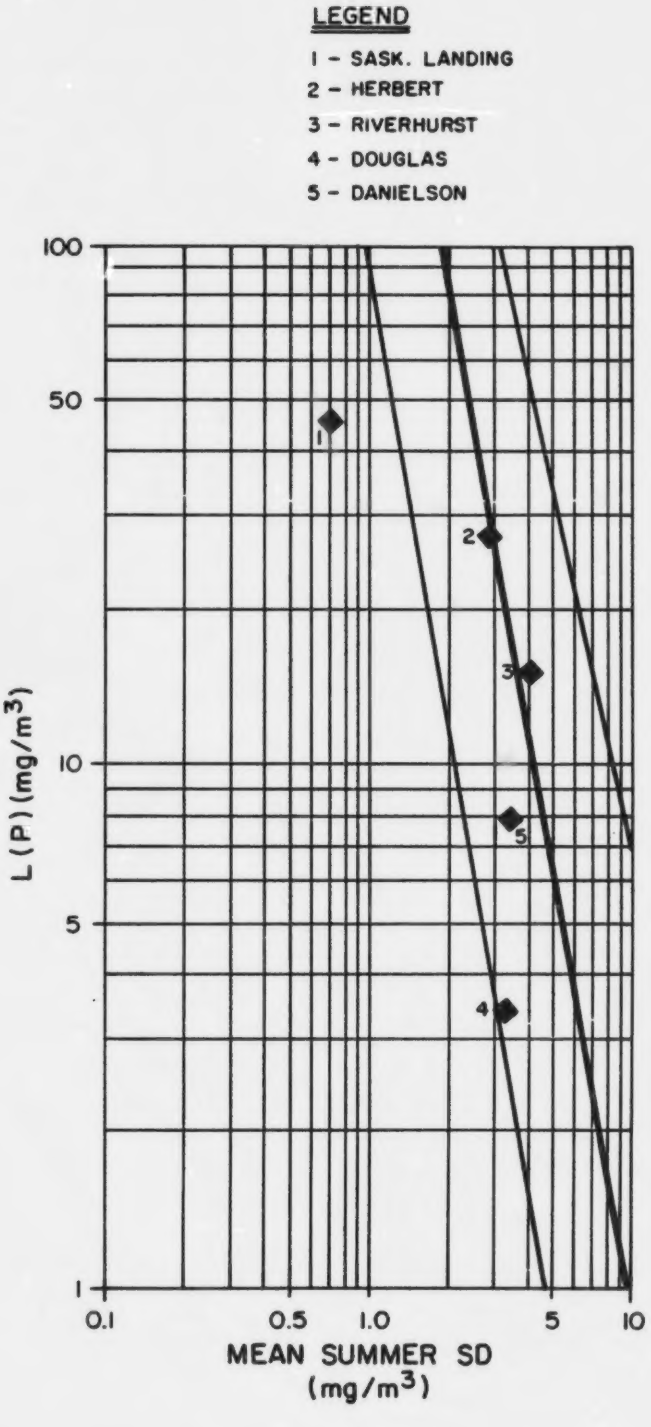


Figure 43 : MEAN SUMMER SECCHI DISK DEPTHS FOR THE FIVE LAKE AREAS COMPARED TO THE OECD (1982) MODEL AND ITS 95 % CONFIDENCE LIMITS.

L[P] = specific loading rate for phosphorus (mg/m^2/y)

L(P) = theoretical phosphorus concentration (mg/M^3) =

$$\frac{L[P]/A/qs}{1 + \sqrt{Tw}}$$

[P] = phosphorus concentration (mg/m^3)

[Chl a] = chlorophyll "a" concentration (mg/m^3)

SD = Secchi depth (m)

Table 22 summarizes several of these parameters for the five sections of the lake and the whole lake.

Table 22

Summary of the Data Used to Develop the Relationships in Equations 5-1 to 5-3

Station	L(P) (mg/m^3)	Mean Summer [P] (mg/m^3)	Mean Summer [Chl a] (mg/m^3)	Mean Summer SD (m)
Sask. Landing	59	50	6	0.72
Herbert	34	25	3	2.85
Riverhurst	13	13	2	4.15
Douglas	7	7*	1	3.3
Danielson	15	15	1	3.5

* Calculated without the value for July 16, 1984 of 100 mg/m^3.

In Table 21 the inflow to the various areas of the lake were determined as follows:

Sask. Landing = Whole Lake (South Saskatchewan River at Lemsford)

Herbert = Sask. Landing - (evaporation-precipitation at Sask. Landing)

Riverhurst = Herbert - (evaporation-precipitation at Herbert)

Douglas = 0.0369 (Riverhurst - (evaporation-precipitation at Riverhurst)

Danielson = 0.9631 (Riverhurst - (evaporation-precipitation at Riverhurst)

The percentage of the Riverhurst flow that enters Douglas and Danielson was determined from data supplied from the Saskatchewan Water Corporation for the study year. These figures should be checked against all the years that data are collected because of the variation in flow from year to year. Evaporation and precipitation figures were obtained from Woodvine (1983).

5.2 Results and Discussion

5.2.1 Trophic Indicator Predictions

The data for model development of trophic indicators is contained in Table 22. The regression analyses for the correlations were done using an HP-41C Stat-Pac (HP). The types of regressions followed the findings of OECD (1982) and the relationships were:

$$[P]_{su} = 10^{(0.427 + \log (L(P))\times 0.66)} \qquad (5\text{-}1)$$

$$[\text{chl a}]_{su} = 10^{(-0.532 + \log (L(p))\times 0.685)} \qquad (5\text{-}2)$$

$$[SD]_{su} = 10^{(0.954 + \log (L(P))\times -0.451)} \qquad (5\text{-}3)$$

Using the methods outlined by Meuller (1983) the standard error of estimation (s_m) was calculated for the three formuli. These are presented in Table 23 with the coefficients of determination and correlation.

Table 23

Summary of the Statistical Parameters
for the Model Formulae

Parameter	S_m	r^2	r
Phosphorus	0.127	0.90	0.95
Chlorophyll	0.141	0.89	0.94
Secchi Disk	0.287	0.45	0.67

Based on the limited number of data points on which the model was developed a more elaborate statistical evaluation was not felt to be warranted. At this point areas of Lake Diefenbaker behave in a similar manner as lakes surveyed in the OECD program. The formulae presented in this section were a refinement of the OECD formulae to better represent the Lake Diefenbaker conditions.

OECD (1982) noted that the Secchi disk data had poor correlation with all other trophic indicators. This was also the case for Lake Diefenbaker. It was hypothesized that SD was not solely caused by chlorophyll "a" concentrations, but by a combination of chlorophyll "a" and suspended inorganic matter, and because the formulae for SD did not include non-filterable residue, or some other measure of suspended inorganic matter, it was not reliable. The correlation coefficient for the phosphorus and chlorophyll vs. L (P) were sufficiently high to give predictions credibility.

The Model and Long-Term Data

Wate_ quality data have been collected on Lake Diefenbaker since 1975. The formulae from section 5.2.1 and the flow and loading data presented in Chapter 3, Section 3.2.2, were used to check the sensitivity of the model. The predicted values were then compared to the measured values for past years. The results for the Saskatchewan Landing area of the lake are summarized in Table 24.

It was concluded that the general predictive capabilities of the model over the 10 year period was poor.

One problem with the above comparisons was that the data in Table 24 for measured values were from the Provincial Water Laboratory and not the Environment Canada Laboratory. When quality assurance sampling was conducted during the study, it was found that there were differences between the two laboratories (Chapter 4, Section 4.2.2). It is not known whether these differences would account for order of magnitude differences between the measured and predicted samples. Several additional years data should be collected to refine the model so it better represents all flow scenarios for the system.

Table 24

Summary of the Measured and Predicted [P] and [chl a] for the Saskatchewan Landing Station from 1975 to 1985

Year	Inflow (m^3)	L[P] (T/year)	Pred. [P] (mg/m^3)	Measured [P] (mg/m^3)	Pred. [chl a] (mg/m^3)	Measured [chl a] (mg/m^3)
1975	5596000000	1,454	128		16	
1976	4467000000	1,900	152		20	
1977	2199000000	261	41	110	5	4
1978	5287000000	1,400	124	80	16	1
1979	4590000000	703	79		10	
1980	6260000000	2,077	162	67	21	5
1981	9250000000	1,534	132	60	17	11
1982	6110000000	1,474	127		16	
1983	4180000000	1,620	137	60	17	1
1984	3095000000	247	50	50	5	6
1985	4320000000	848	114		14	

5.2.2 Present Lake Trophic State

OECD (1982) has developed a series of graphs that represent the probability distribution for the three trophic indicators and categories. Using these graphs and the mean annual [P] and [chl a] the probability of the lake areas being classified in one of the five trophic categories was determined. These probabilities are presented in Table 25.

The interpretation of Table 25 is as follows: looking under the phosphorus loading probabilities one sees that, at Saskatchewan Landing the probability of the lake being oligotrophic is 0.08, the probability of it being mesotrophic is 0.55 and the probability of it being eutrophic is 0.32. Looking at the probabilities for phosphorus and chlorophyll "a" in Table 25, it was found that except for Saskatchewan Landing, all areas of the lake are most likely to be mesotrophic or oligotrophic. At Saskatchewan Landing the lake area is most likely to be mesotrophic or eutrophic.

Maintenance of Present Trophic Status

It is the policy of Saskatchewan Environment and Public Safety that the trophic status of Lake Diefenbaker should not fall below mesotrophic at any location. The above analysis of the trophic status of the lake in 1984-1985 indicated that the Saskatchewan Landing area of the lake was mesotrophic with a high probability of being eutrophic. It could, therefore, be stated that this was the maximum permissible state of degradation, and that objectives should be set to prevent further degradation of the lake.

The probability curves presented in Rast and Lee (1978) were used to find the [P] and [chl a] that would prevent further degradation. Using Table 25 it was considered appropriate that the probability of the lake at Saskatchewan Landing not exceeding mesotrophic status should be 0.50. At this probability the concentrations of phosphorus and chlorophyll "a" were determined as 20 mg/m^3 and 3 mg/m^3, respectively.

Table 25

The Probabilities of the Lake Areas Being in a Trophic Category Based on the Parameter Levels Averaged for the Study Period, 1984-85

Station	Measured Concen. (mg/m^3)	Ultra-Oligo-trophic	Oligo-trophic	Meso-Trophic	Eutrophic	Hyper-Trophic
			Phosphorus			
Sask. Landing	50	0	0.08	.55	0.32	0.01
Herbert	25	0.01	0.32	0.58	0.07	0
Riverhurst	13	0.03	0.47	0.47	0.03	0
Douglas	7	0.01	0.30	0.58	0.10	0
Danielson	15	0.05	0.60	0.32	0.01	0
			Chlorophyll "a"			
Sask. Landing	6	0	0.07	0.43	0.43	0.07
Herbert	3	0	0.18	0.60	0.21	0.01
Riverhurst	2	0.07	0.47	0.42	0.02	0
Douglas	1	0.19	0.62	0.19	0	0
Danielson	1	0.19	0.62	0.19	0	0

It should be understood that the above values were derived from a graph that was developed from mean annual values, and the model in Section 5.1.2 was developed from, and for, mean summer values. An examination of the data shows that these two means were close enough to be used interchangeably. This should be reconsidered when the model is refined.

5.2.3 Critical Loadings for Phosphorus

In Section 5.2.2 it was determined that to maintain the trophic level of Lake Diefenbaker at mesotrophic it would be necessary to have a concentration of phosphorus in the area of Saskatchewan Landing no higher than 20 mg/m^3. OECD (1982) gave the formula to estimate the phosphorus loading L[P] necessary to maintain a critical [P] as;

$$L[P] = ((P)_c/Tw)*Z*A \qquad (5\text{-}4)$$

where $(P)_c$ = critical concentration of phosphorus

As one can see from the formula the L[P] is dependent on a variable Tw which in turn is dependent on the inflow to the system. This means that the L[P] will vary with the yearly flow and therefore a fixed L[P] as a water quality objective will not guarantee that the critical level for phosphorus would be maintained. Table 26 summarizes the phosphorus loading to the Saskatchewan Landing area necessary to maintain the [P] = 20 mg/m^3 for various flow conditions.

Table 26

Loading of P That Would Maintain the [P] = 20 mg/m^3

Annual Inflow (m^3)	Critical L[P] (Tonnes/year)
2.3×10^9	47.29
3.1×10^9	63.05
3.9×10^9	78.81
4.7×10^9	94.58
5.5×10^9	110.34
6.3×10^9	126.10
7.1×10^9	141.86
7.9×10^9	157.63
8.6×10^9	173.39
9.5×10^9	189.15
1.0×10^{10}	204.91
1.1×10^{10}	220.68

IWD (1985) gives the average annual flow at Lemsford as 256 m^3/s. This would mean a critical loading of approximately 160 tonnes/year. The average annual flow leaving Alberta (the sum of the South Saskatchewan River and Red Deer River) is 230 m^3/s which would mean a critical loading at the border of 130 tonnes/year. If these critical loading figures were used as the objective, in years when the flows were over these averages the [P] in the Saskatchewan Landing area of Lake Diefenbaker would be lower than the $[P]_c$; conversely in years when the flows were below these levels the [P] at Saskatchewan Landing would be higher than the $[P]_c$.

Chapter 3, Section 3.2.2 shows that for 3 of the 11 years examined, the flow at the Alberta border was higher than the average. This means that for 8 of those years the critical loading for Saskatchewan Landing would be exceeded at the border.

The Prairie Provinces Water Board (PPWB) has developed a draft Water Quality Indicator for total phosphorus loading at the Alberta border of 285 tonnes/year (South Saskatchewan River and Red Deer River combined). This was based on a phosphorus loading for the whole lake of 0.74 g P/m^2/year, as determined from Vollenweider relationships for excessive phosphorus loading and mean depth/hydraulic residence time (PPWB, 1987). If the Vollenweider relationships for permissible loading are used the desirable loading at the Alberta border would have been 140 tonnes/year. The approaches used by the present study and the PPWB were different but the resulting L[P] was similar for the average flow year.

In view of the results of the present study it is evident that total phosphorus loading to Lake Diefenbaker is already high. Negotiations should be held with Canada, Alberta and Saskatchewan to prevent further increases in TP loading and to examine feasible options for protecting the long-term quality of Lake Diefenbaker.

6. LAKE BIOLOGY

6.1 Phytoplankton

Phytoplankton are important components of aquatic systems. The significance of phytoplankton in nutrient cycling and energy flow prescribes their inclusion in assessments of the stability and balance of aquatic systems. In large deep lakes or reservoirs such as Lake Diefenbaker, the plankton are the major primary link in the trophic relationship.

The community structure of the phytoplankton assemblage can also be used as an indicator of the trophic status of lakes (Fruh et al., 1966; Hutchinson, 1967; Lund, 1969). Oligotrophic systems generally have a high species diversity, but low overall cell density and dominance, with few seasonal pulses. Oligotrophic waters are also usually associated with a wide variety of taxa. In contrast, eutrophic systems are characterized by lower species diversity and high standing crop comprised primarily of a few Cyanophyte (blue-green algae) species.

6.1.1 Species Composition

The taxonomy of the phytoplankton population observed within Lake Diefenbaker is summarized in Table 27. A total of 106 algal taxa were observed during the July, 1984-June, 1985 study period. Seventy-five taxa were positively identified to species level while thirty-one were identified only to genus. The 106 algal taxa identified represented 68 genera.

Table 27

Phytoplankton Genera and Species Observed in
Lake Diefenbaker, 1984-1985 (n = 106).

CHLOROPHYTA (n = 43)
(Green Algae)

Actinastrum gracilimum
Ankistrodesmus falcatus
Chlamydomonas sp.
Cladophora fracta
Closterium sp.
Coelastrum cambricum
C. microporum
Cosmarium sp.
Crucigenia apiculata
C. quadrata
C. tetrapedia
Dictyosphaerium pulchellum
D. simplex
Elaktothrix gelatinosa
Eudorina elegans
Gonium pectorale
G. sociale
Kirchneriella lunaris
K. obesa
Lagerheimia quadriseta
L. subsalsa
Monoraphidium contortum
Oocystis borgei
O. gigas
O. solitaria
Pandorina morum
Pediastrum boryanum
P. duplex
P. obtusum
P. simplex
P. tetras
Quadrigula chodatii
Scenedesmus acuminatus
S. arcuatus
S. bijuga
S. ecornis
S. quadricauda
Scenedesmus sp.
Selenastrum sp.
S. bibraianum
S. gracile
Spirogyra weberi
Staurastrum sp.

CYANOPHYTA (n = 20)
(Blue-green Algae)

Anabaena flos-aquae
A. spiroides
Aphanizomenon flos-aquae
Aphanocapsa sp.
Aphanothece sp.
Chroococcus dispersus
C. limneticus
Coelosphaerium kuetzingianum
C. naegelianum
Gloeocapsa sp.
Gomphosphaeria aponina
Gomphosphaeria sp.
Marssoniella elegans
Merismopedia elegans
M. glauca
Microcystis aeruginosa
M. flos-aquae
Microcystis sp.
Oscillatoria tenius
Spirulina sp.

Table 27 (continued)

BACILLARIOPHYTA (n=27)
(Diatoms)

Asterionella formosa
Centronella sp.
Cocconeis pediculus
Cymatopleura sp.
Cymbella sp.
Diatoma elongatum
Diatoma sp.
Fragilaria crotonensis
Gomphonema sp.
Gyrosigma sp.
Melosira granulata
Meridion circulare
Navicula sp.
Nitzschia acicularis
N. linearis
Nitzschia sp.
Rhoicosphenia curvata
Rhopalodia gibba
Stephanodiscus astrea
Surirella ovalis
S. ovata
Surirella sp.
Synedra acus
S. ulna
Synedra sp.
Tabellaria fenestrata
Tropidoneis sp.

CHRYSOPHYTA (n = 6)
(Yellow-green Algae)

Dinobryon sertularia
D. sociale
Mallomonas acardoides
Mallomonas sp.
Synura uvella
Tribonema utriculosum

EUGLENOPHYTA (n=4)
(Euglenoids)

Euglena sp.
Phacus sp.
Trachelomonas robusta
Trachelomonas sp.

PYRRHOPHYTA (n = 6)
(Dinoflagellates)

Ceratium hirundinella
Cryptomonas sp.
Gymnodinium sp.
Peridinium cinctum
Peridinium sp.
Rhodomonas sp.

Species abundance has been shown to decrease with nutrient enrichment (Patrick *et al.*, 1954). The relatively high phytoplankton species abundance observed during this study period is characteristic of a mesotrophic (intermediate in productivity) to oligotrophic (low in productivity) system.

The greatest species abundance (43 spp.) occurred within the phylum Chlorophyta (green algae). The phyla Bacillariophyta (diatoms) and Cyanophyta (blue-green algae) were represented by 27 and 20 species respectively. Euglenophyta (euglenoids) accounted for only four algal varieties (see Table 27).

Seasonal Abundance and Composition

As with total species numbers observed, the phylum Chlorophyta was also dominant on the basis of seasonal species abundance. The mean number of Chlorophyta species observed during the 14 sampling periods was 21 (42% by composition). This compared with a mean of only 13 spp. and 8 spp. for the Bacillariophyta and Cyanophyta respectively. Euglenophyta had a seasonal mean abundance of only 2.2 species. No Euglenophyta species were observed during the February 18, 1985 survey period.

Seasonal trends regarding overall phytoplankton species abundance are presented in Figure 44. Total species abundance (all phylums and sampling sites combined) was highest during mid-July (68 spp.) and August (69 spp.) of 1984. The lowest total species abundance (28 spp.) was observed during March, 1985. Species abundance also was low during the January and February surveys. Both species number and mean phytoplankton biovolume (see Figure 58) were lowest during the winter months. This is likely a reflection of less vigorous growth under conditions of low water temperature and reduced light (ice cover).

Figure 45 compares the seasonal species richness of the more abundant phylums Chlorophyta, Bacillariophyta and Cyanophyta. The number of Chlorophyta and Bacillariophyta species observed during each sampling period were consistently higher than that for the phylum Cyanophyta. As indicated in Figure 59, the seasonally observed number of Chlorophyta and Cyanophyta species were closely correlated ($r = 0.95$). This demonstrates that the seasonal species richness of these phyla remained similar on a proportionate basis. Seasonal Chlorophyta and Cyanophyta species numbers also were closely correlated with overall (all phylums combined) seasonal species number. These correlation coefficients were both $r = 0.98$.

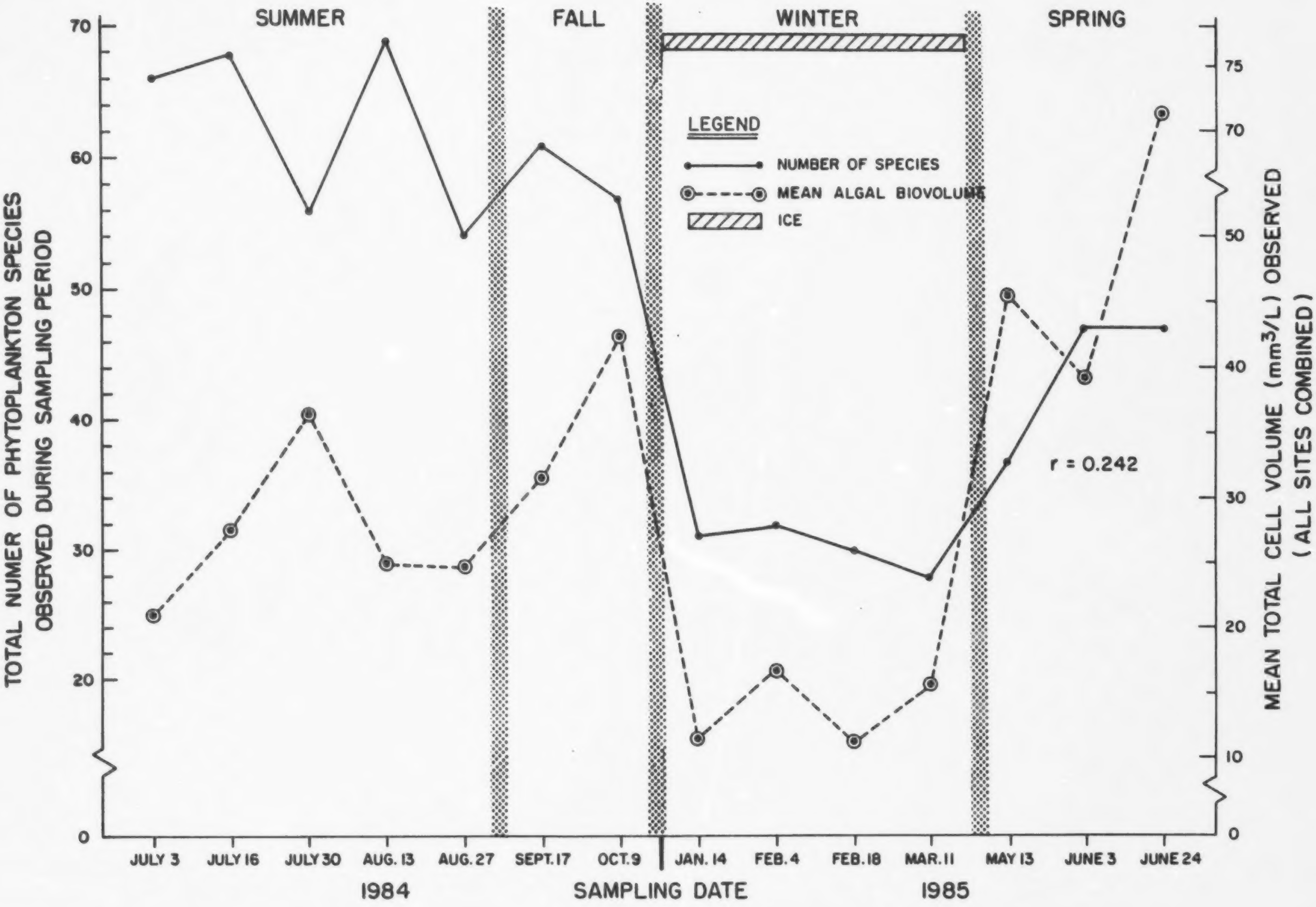


Figure 44 : SEASONAL TOTAL PHYTOPLANKTON SPECIES DIVERSITY VS MEAN SEASONAL BIOVOLUME OBSERVED AT LAKE DIEFENBAKER (ALL SAMPLING SITES AND PHYLA COMBINED) 1984 - 1985

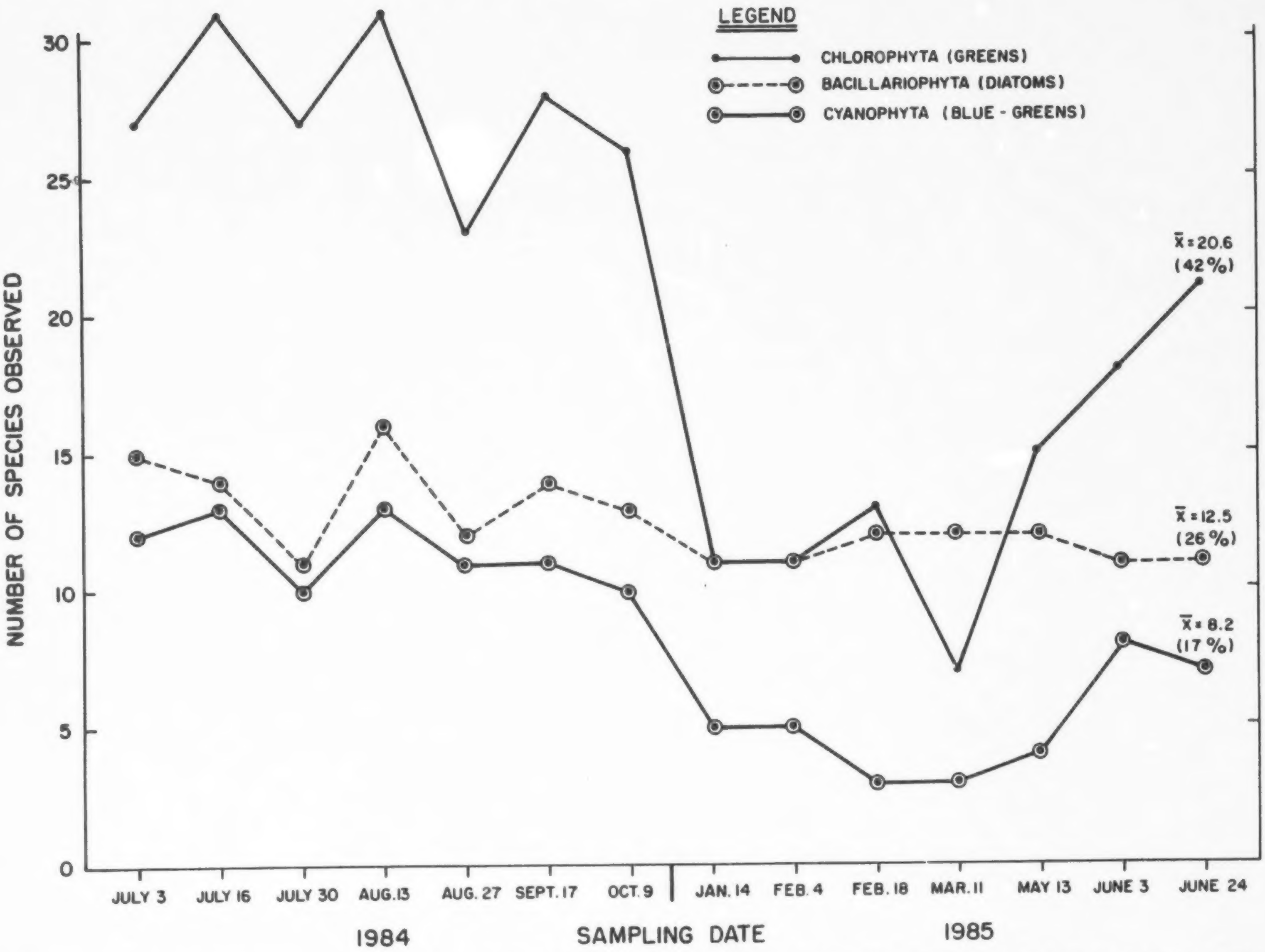


Figure 45 : SEASONAL SPECIES ABUNDANCE OBSERVED WITHIN THE PHYLUMS BACILLARIOPHYTA, CHLOROPHYTA AND CYANOPHYTA AT LAKE DIEFENBAKER (ALL STATIONS COMBINED) 1984 - 1985

The highest species abundance within all three phyla illustrated in Figure 45 was observed during the July 16, 1984 and/or August 13, 1984 sampling periods. Species number for the Chlorophyta and Cyanophyta were lowest during the March 11, 1985 sampling period. The similarity in the seasonal trends between the different phyla further indicates that their relative per cent species composition did not vary considerably throughout the study period. This also suggests that general water quality did not change significantly during the study period. The only exception to this trend occurred during the March 11, 1985 survey when Bacillariophyta species abundance was highest overall (12 spp; 43% by composition). However, the number of Bacillariophyta species had not increased during this period. Instead, the increase in the per cent species composition of this phylum was due to a sharp decline in the number of Chlorophyta species observed during March, 1985. The number of species present within the three phyla remained constant between the January 14 to February 4, 1985 surveys (see Figure 45). Species composition did, however, change during these two survey periods.

Algal abundance expressed in terms of cell volume or biovolume is a better indicator of phytoplankton biomass standing crop than is cell density. Cell density results can be an exceedingly poor measure since cell size often varies greatly between species and phyla. This is evidenced by the poor correlation (r = 0.57) observed between seasonal mean biovolume and cell density. An example in case is that the Chlorophytes displayed the highest seasonal species abundance and mean cell density, however, Cyanophytes consistently accounted for the highest seasonal mean biovolume during all survey periods (see Figure 46).

On an overall mean basis, Cyanophyta composed 79% of the total seasonal algal biovolume (Figure 46). In contrast, Chlorophyta had only the fourth highest seasonal mean biovolume (4% by composition) when compared to the other algal phyla. This position was reversed with Cyanophyta with respect to mean seasonal cell density (Figure 47). The order of magnitude regarding algal biovolume and density remained consistent between the other algae phyla.

Mean seasonal biovolume (all phyla combined) is presented in Figure 44 along with seasonal species abundance. Figure 44 indicates that algal species abundance and biovolume both declined sharply during the winter survey periods. However, the overall seasonal correlation between the two parameters was poor (r = 0.24). The

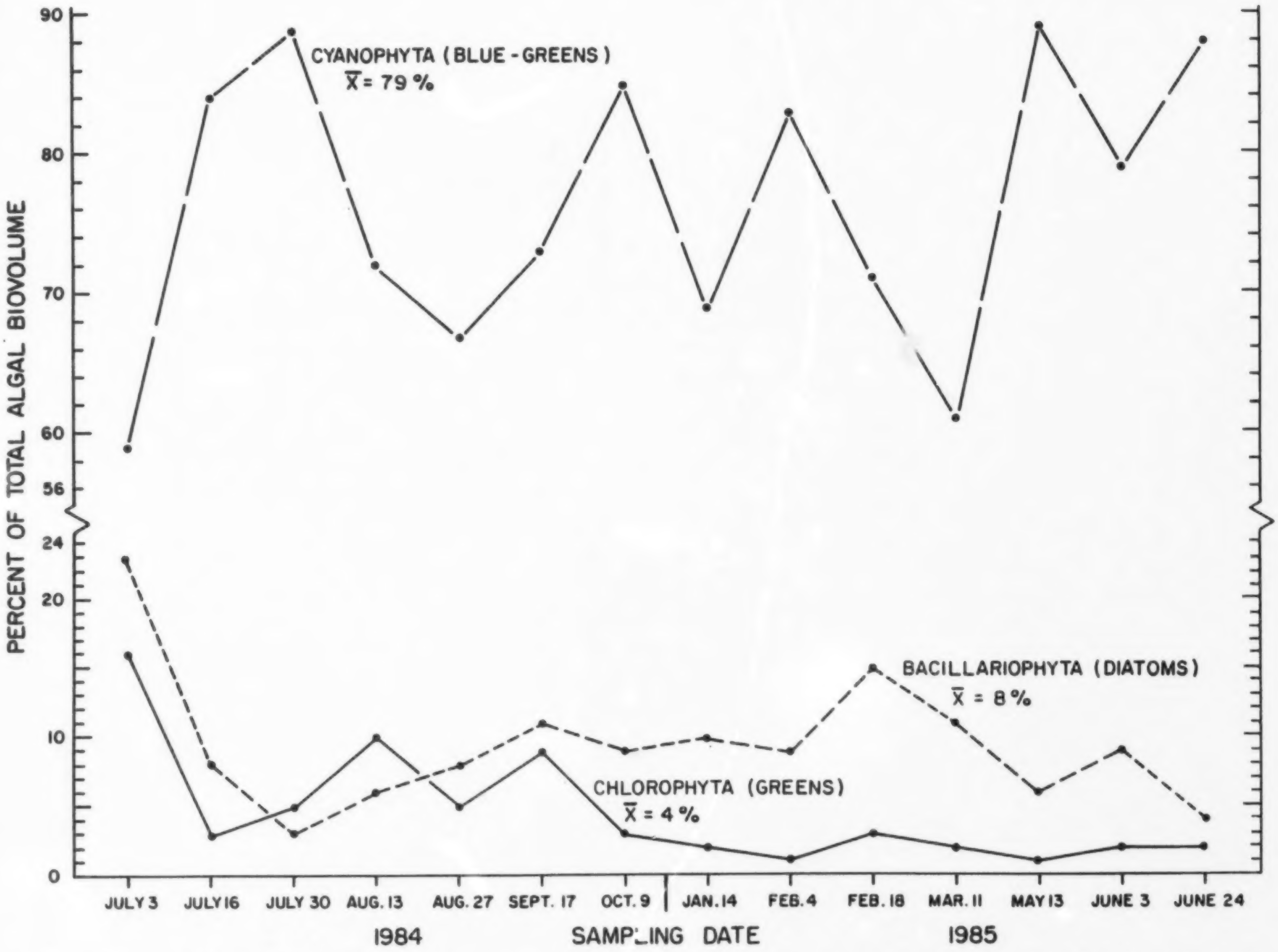


Figure 46 : SEASONAL RELATIVE (PERCENT) VOLUMETRIC ABUNDANCE OF CHLOROPHYTA, CYANOPHYTA AND BACILLARIOPHYTA IN LAKE DIEFENBAKER (ALL SAMPLING STATIONS COMBINED) 1984-1985

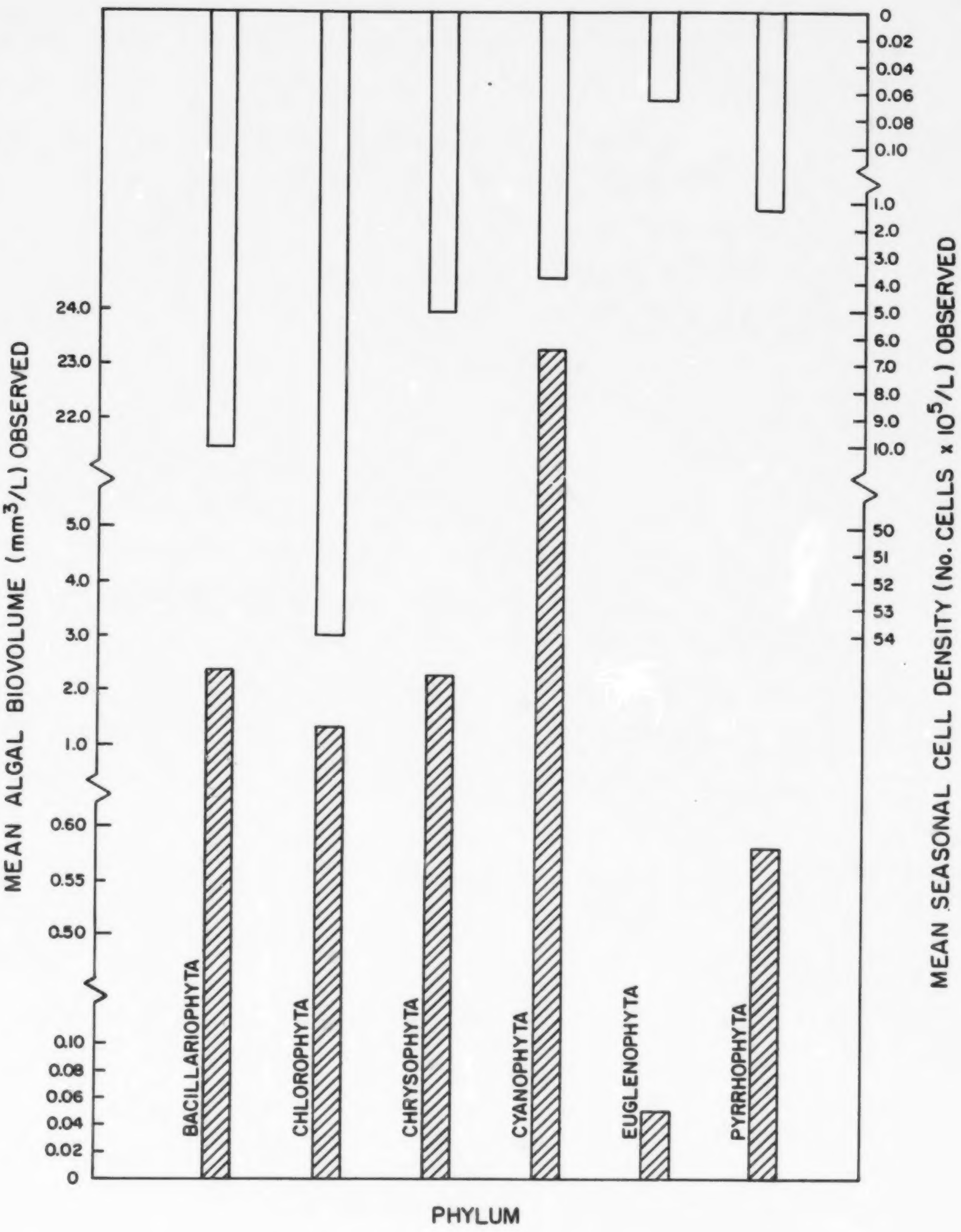


Figure 47: OVERALL MEAN ALGAL BIOVOLUME AND DENSITY OBSERVED WITHIN EACH PHYLUM AT LAKE DIEFENBAKER (ALL SAMPLING STATIONS AND PERIODS COMBINED) 1984-1985

declines from October, 1984 levels observed during winter 1985 were due, at least in part, to the growth limiting effects of ice cover and the inherent reduction in light availability. This low phytoplankton biomass observed during winter 1985 also may have accounted for the relatively high dissolved nitrogen levels recorded (see Section 4.2.2).

Seasonal phytoplankton biovolume was lowest during the February 18, 1985 survey and highest during the June 24, 1985 survey. Other peaks occurred during the July 30, 1984, October 9, 1984 and May 13, 1985 sampling periods. The rate of phytoplankton production determines the cyclical period during which populations rise, decline and subsequently rise again (Lund, 1969). Figure 44 indicates that relatively few population pulses occurred and that the cycle periods were moderately long. These growth characteristics correspondingly indicate that only a moderate rate of phytoplankton production occurred within Lake Diefenbaker during the study period.

Spatial Abundance and Composition

Spatial trends regarding phytoplankton species abundance are summarized in Table 28. The phylum Chlorophyta was the most diverse algal group observed at all six sampling stations. This is consistent with the trend noted in

Section 6.1 where Chlorophyta also had demonstrated the highest seasonal species abundance. The greatest number of Chlorophyta species observed at any one station (40 spp.) occurred at Station 2. The phyla Bacillariophyta, Chrysophyta, and Cyanophyta also demonstrated their highest species richness at this station. Reflecting this, the greatest total number of algal species (90 spp.) was observed at Station 2. Total mean algal biovolume, however, was ranked only fifth at Station 2. The second highest total species richness (74 spp.) was noted at Station 4. A low of only 44 algal species were observed at Station 1. Low species abundance at Station 1 may have been due to turbid waters and considerable mixing action.

Although the total number of algal species observed differed considerably between sampling sites, the relative proportions represented by each phylum remained quite similar from one station to the next. This was particularly evident with respect to the phyla Bacillariophyta, Chlorophyta and Cyanophyta (see Table 28). These results indicate that proportionate algal composition on a per phyla basis remained relatively consistent between sampling stations despite major differences in observed species diversity.

Table 28

Total Number[1] of Phytoplankton Species Observed Within Each Phylum at Each Sampling Station in Lake Diefenbaker, 1984-85

	Sampling Station Number					
Phylum	1	2	3	4	5	6
Bacillariophyta	5 (11%)	24 (27%)	13 (21%)	16 (22%)	16 (26%)	15 (26%)
Chlorophyta	26 (59)	40 (44)	27 (43)	32 (43)	24 (39)	24 (42)
Chrysophyta	1 (2)	5 (6)	3 (5)	3 (4)	3 (5)	2 (4)
Cyanophyta	8 (18)	15 (17)	13 (21)	14 (19)	12 (20)	11 (19)
Euglenophyta	2 (5)	3 (3)	4 (6)	3 (4)	2 (3)	1 (2)
Pyrrhophyta	2 (5)	3 (3)	3 (5)	6 (8)	4 (7)	4 (7)
Total No. Species	44	90	63	74	61	57
Rank	6	1	3	2	4	5

[1] Brackets indicate the proportion of the total number of algal species observed at that sampling station.

The total relative (per cent) volumetric composition of phytoplankton phyla within Lake Diefenbaker (all sampling periods combined) is presented in Table 29. The phylum Cyanophyta represented the highest proportion of mean cell volume at all sampling stations. In contrast Chlorophyta, which had the highest species diversity and mean cell density at all stations, was only fourth most abundant on the basis of cell volume. These results are consistent with the trend noted in the previous discussion of seasonal algal biovolume. Note that the volumetric dominance of Cyanophyta observed at all six primary sampling locations should not be used to infer that eutrophic conditions prevail at these sites. Although the generality "Eutrophic waters are likely to have more planktonic Cyanophyta than oligotrophic waters" usually holds true, it is the overall quantitative volume that is of issue. Little is known as to what actually controls the qualitative composition of phytoplankton. The volumetric dominance of Cyanophyta in Lake Diefenbaker can likely be attributed in part to the relatively large cell size characteristic to most blue-green algae taxa (e.g. Anabaena spp.). Lund (1967) demonstrated that blue-green algae often can dominate volumetrically in oligotrophic waters due to their relatively large size and hence their greater freedom from zooplankton grazing. Smaller algae types such as the chlorophytes can be significantly reduced by zooplankton community.

Total mean algal biovolume was highest at Stations 3 and 4, and lowest at Stations 1 and 2 (see Figure 48). Station 1 also had represented the lowest species abundance observed at any station, possibly a reflection of high turbidity and/or less stable conditions due to greater water mixing rates. The river-like

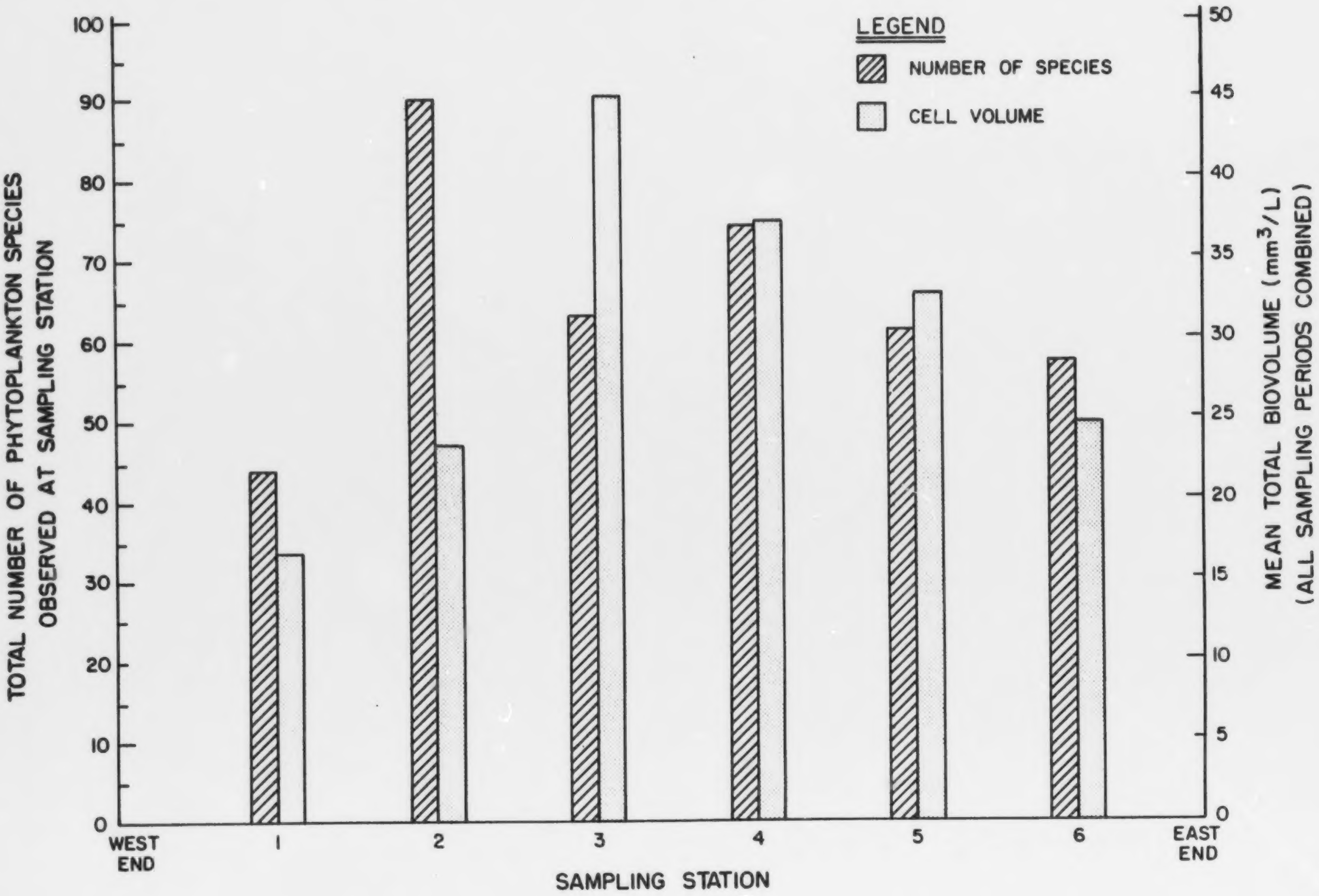


Figure 48 : SPATIAL TRENDS REGARDING TOTAL PHYTOPLANKTON SPECIES ABUNDANCE AND MEAN TOTAL ALGAL BIOVOLUME OBSERVED AT LAKE DIEFENBAKER (ALL SAMPLING PERIODS COMBINED) 1984 - 1985

characteristics at this site allow for rapid movement of algal populations in a downstream direction. Total mean biovolume declined steadily from Stations 3 to 6 suggesting lower productivity at the downstream end of the reservoir. Secchi transparency (see Section 4.2.2) was greatest at Stations 4-6 supporting these results.

Also, mean nitrogen levels, both total and particulate decreased from Stations 3 to 6 (see Section 4.2.2). This data also is consistent with the chlorophyll "a" trend of reduced levels from Station 3 east.

Table 29

Total Relative (per cent) Volumetric Composition[1] of Phytoplankton Phyla Within Lake Diefenbaker, 1984-85 (all sampling periods combined).

	Sampling Station Number					
Phylum	1	2	3	4	5	6
Bacillariophyta	9%	8%	12%	8%	6%	5%
Chlorophyta	6 (86)	7 (80)	4 (68)	3 (63)	4 (57)	5 (63)
Chrysophyta	8	5	4	6	12	14
Cyanophyta	76 (5)	79 (8)	79 (2)	82 (4)	74 (4)	73 (4)
Euglenophyta	N	N	N	N	N	NF
Pyrrhophyta	1	1	1	1	4	3

[1] Brackets indicate per cent composition based on cell density.
N - Negligible
NF - None Found

In summary, the spatial characteristics observed regarding species composition and algal biovolume suggest that the trophic status of Lake Diefenbaker, while not eutrophic, is moderate and varies depending on location. Results indicate that the trophic status is somewhat mesotrophic in the upper half of the reservoir and becomes progressively more oligotrophic toward the downstream end. Trophic status appears to be highest at Stations 3 and 4 based on the phytoplankton data. This is fairly consistent with the findings based on chlorophyll "a" concentrations as discussed in Section 4.2.2.

6.2 Bacteria

Bacteria, as well as other types of microorganisms, are present in all surface waters. In the natural setting, the bacteria population of lakes is comprised of aquatic species that grow in the lake and/or are derived from tributaries. Most of these truly aquatic species, as well as most of those derived from inputs from the terrestrial environment, are harmless. These play important roles in the synthesis or degradation of organic matter, or in the cycling of essential nutrients.

Still other bacteria, of sanitary or health significance, may be present in lakes mainly as the result of direct or indirect inputs of fecal material from animals and humans, as well as from discharges of various types of wastewater (e.g. stormwater, sewage). When the densities of these microbes become excessive, the bacteriological quality of the water may be impaired, and the recreational, agricultural or domestic use potential of the water threatened. In order to assess the bacteriological quality of surface waters specific groups of indicator bacteria (e.g. total and fecal coliforms, fecal streptococci) are enumerated. When these bacteria are present at or above objective levels these results are considered indicative of the likely presence of disease-causing microbes. Waters with such levels of indicator bacteria may be considered to be unsuitable for various types of usage.

In Saskatchewan the bacteriological quality of surface waters is assessed using various objectives for the indicator bacteria total coliforms (TC) and fecal coliforms (FC) (Saskatchewan Environment, 1983). In addition, fecal streptococci (FS) are also enumerated to provide supportive evidence of the fecal origin of the TC and FC species that may be detected. The subject of indicator bacteria is discussed in detail in a previous report concerning the North Saskatchewan River near Prince Albert (Saskatchewan Environment, 1984).

During the present study, indicator bacteria densities were determined on a seasonal basis at six mid-lake locations on Lake Diefenbaker. In nearly every instance the highest mean and single-sample maximum densities were observed for each indicator group during the summer seasons of 1984 and 1985. For this reason, and because of the greatest incidence of recreational usage of the lake occurring in this season, the following presentation emphasizes the bacteriological data pertaining to the summer periods.

The bacteriological results for the summer periods of 1984 and 1985 have been presented in Figures 49, 50 and 51, respectively. It should be noted that these data represent the bacteriological quality of lake water at mid-lake locations, which generally would not be influenced significantly by most types of on-shore or near-shore human activity.

It is apparent in Figure 49 that mean TC levels at all six mid-lake stations were below the maximum acceptable level concerning contact reacreational or other uses of the water.

Mean levels of TC, however, were considerably higher at the three upstream sites (e.g. 370-510 TC/100 ml) than at the three mid-lake sites in the lower reaches of the lake (e.g. 9-36 TC/100 ml). Also, individual results for Stations 1 and 2 (e.g. those recorded as greater than 2,000 TC/100 ml) suggest a potential for the existing provincial surface water quality objective limit pertaining to recreational/vegetable crop irrigation (e.g. 2400 TC/100 ml in a single sample) to be

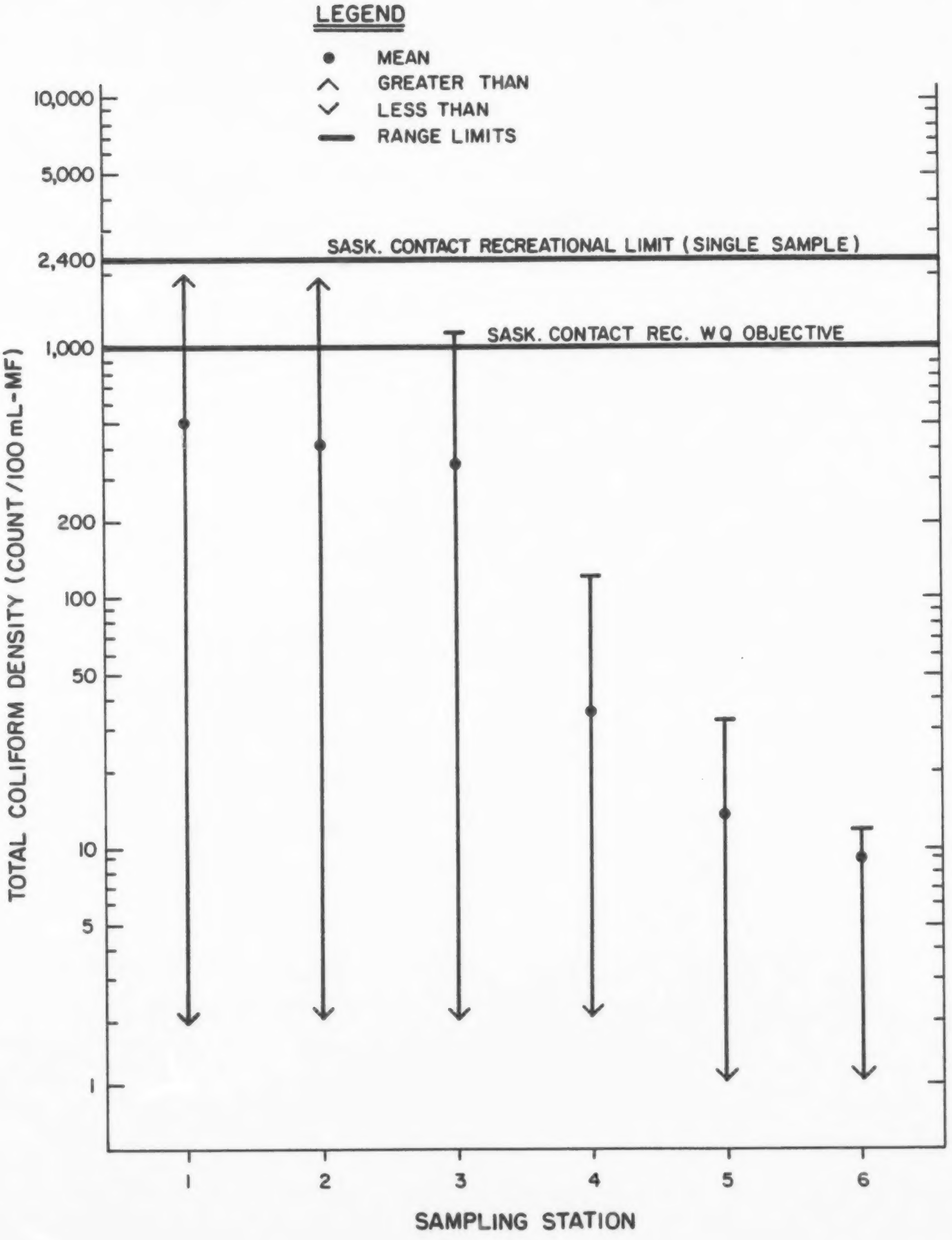


Figure 49: TOTAL COLIFORM DENSITIES AT MID-LAKE STATIONS ON LAKE DIEFENBAKER DURING SUMMER PERIODS OF 1984-1985

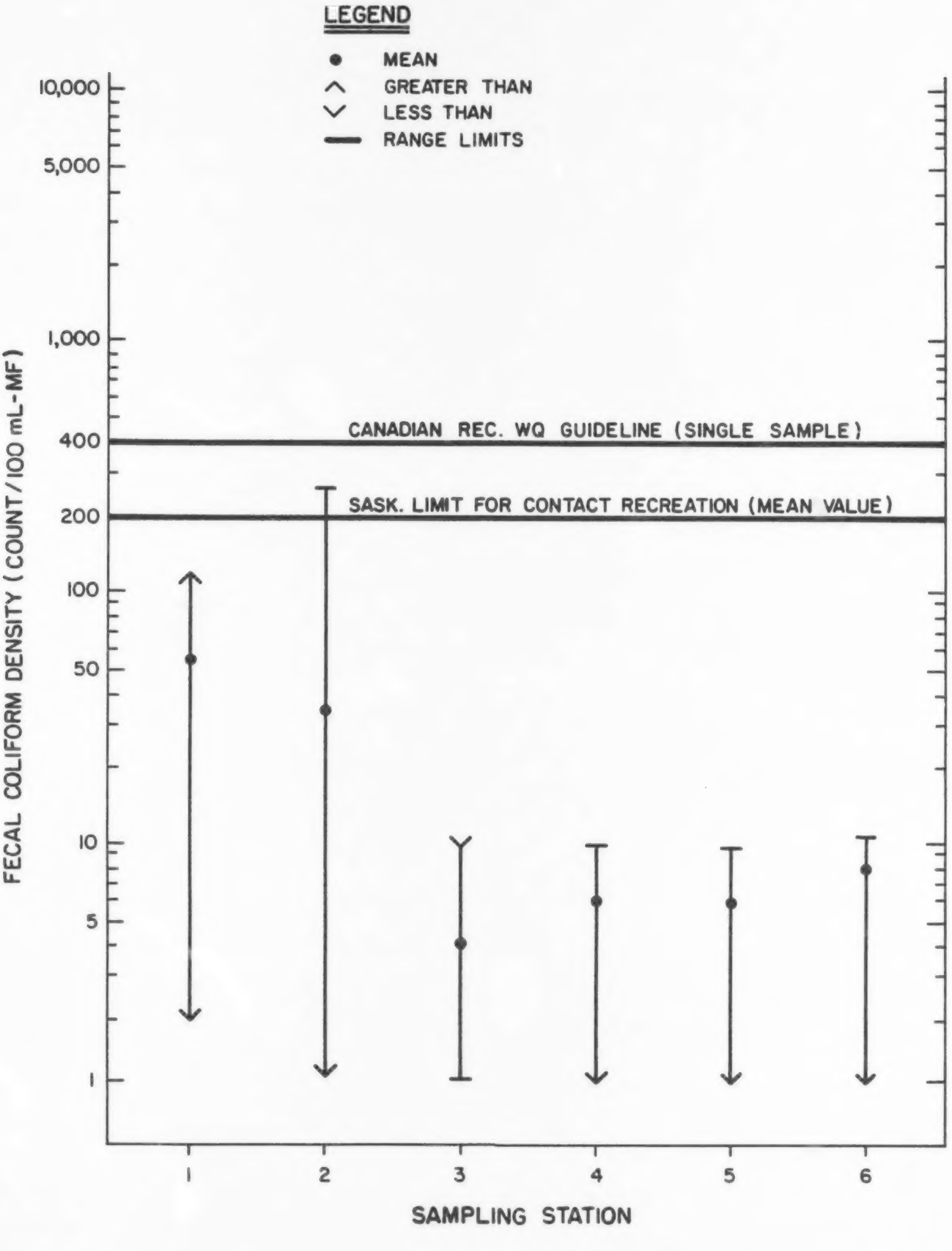


Figure 50: FECAL COLIFORM DENSITIES AT MID-LAKE STATIONS ON LAKE DIEFENBAKER DURING SUMMER PERIODS OF 1984 - 1985

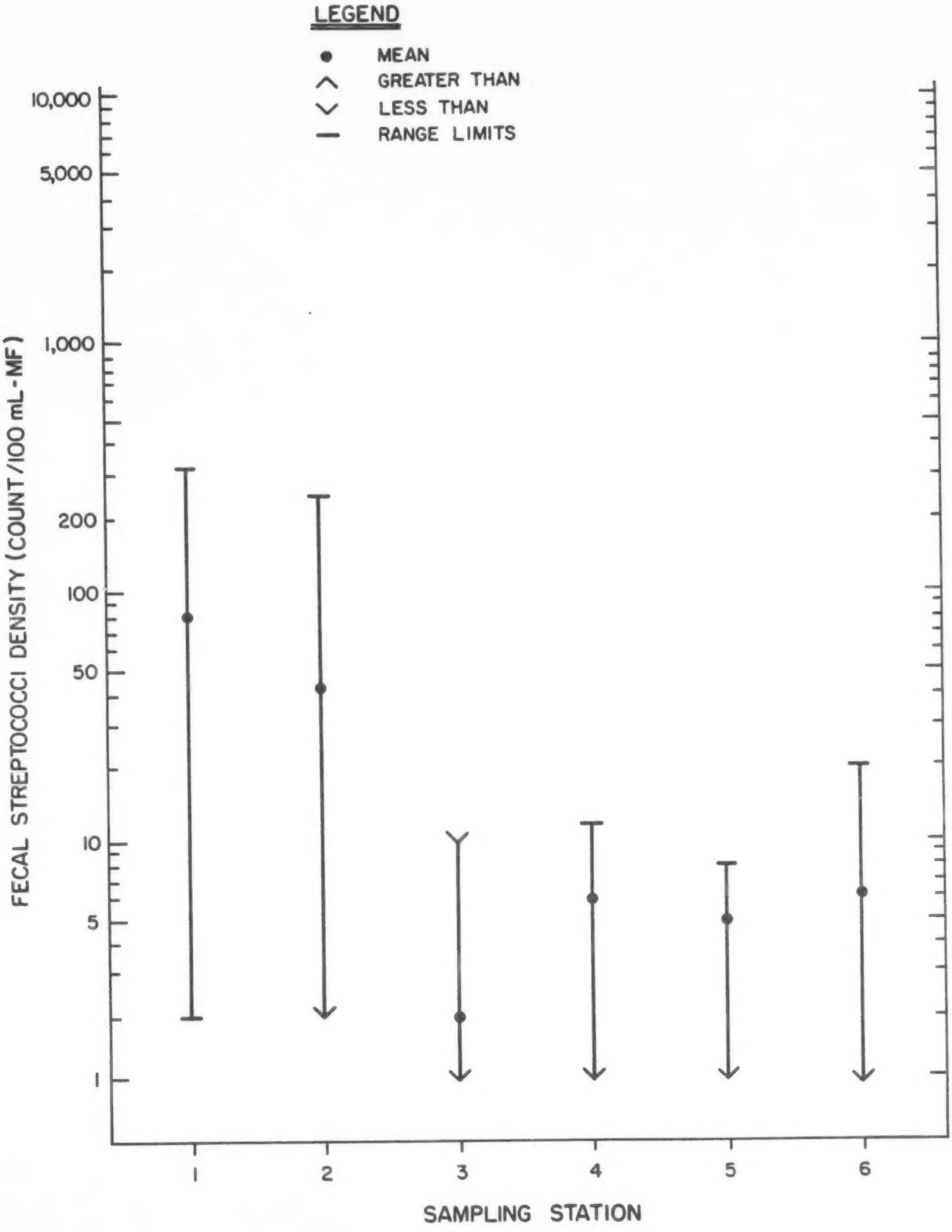


Figure 51 : FECAL STREPTOCOCCI DENSITIES AT MID-LAKE STATIONS ON LAKE DIEFENBAKER DURING SUMMER PERIODS OF 1984 - 1985

exceeded occasionally. Similar high TC values for individual samples have been recorded in previous monitoring of the lake (historical data). In general, however, the TC levels observed at mid-lake stations suggest a water quality suitable for all uses addressed in the provincial surface water quality objectives (Saskatchewan Environment, 1983).

Although the TC group is still used extensively for the assessment of surface water quality it is now widely recognized that the results obtained with this indicator system are of limited sanitary significance. Since bacteria of non-fecal origin (e.g. those TC derived from vegetation and soil) and even non-enteric species (e.g. Aeromonas hydrophila) present in surface water may yield positive TC results, the TC indicator is of limited value in assessing the true sanitary status of surface waters. High TC levels in a water body are, however, an indicator of potential water quality impairment if similar levels of the other indicator groups (e.g. FC, FS) are also present. Two previous reports (Saskatchewan Environment, 1984a [Wascana Creek, WPC 39], and 1984 [NSR PA, WPC 40]) have presented detailed discussion of the limitations of the TC indicator group.

FC results for most surface waters, especially at mid-lake locations (e.g. those sites distant from shoreline influences) are considered a more reliable indicator of the sanitary status of water bodies (see Saskatchewan Environment, 1984a, 1984). The FC data for 1984-85 display a trend for generally higher mean and maximum levels in the upper portion of Lake Diefenbaker as was noted for the TC results (Figure 63). FC levels at Stations 3-6 were low and indicative of water with little fecal contamination. These results suggest waters from mid-lake to be of high quality and to be suitable for all uses addressed in the existing provincial surface water quality objectives (Saskatchewan Environment, 1983).

As already noted for the summer TC and FC results (Figure 49 and 50) the FS results for the same seasonal period (Figure 51) display a trend of higher mean and maximum levels for Stations 1 and 2 in the upper reaches of the study area. Generally very low levels of FS (e.g. less than 10/100 ml), very similar to the levels of FC observed, characterized the bacteriological quality of mid-lake Stations 3-6. These results for FS provide supporting evidence of the high bacteriological quality of mid-lake waters indicated by the FC results.

Among historical data concerning these mid-lake regions of the lake, only occasionally have the levels of TC exceeded existing surface water quality objectives. These exceedences have occurred mainly during summer periods when levels of bacteria that yield positive TC results are present in greatest numbers in the warmer waters or in fall when similar bacteria may increase in number in response to greater available quantities of decaying plant/animal material.

The results show the lower reach of the lake (Stations 3-6) to be of generally higher bacteriological quality than the upper reach. Stations 1 and 2 in particular, appear to be subject to greater levels of all three indicator bacteria. The reasons for this are uncertain but may be due to the generally higher trophic status, and higher levels of algae, which may support the growth/survival of indicator bacteria and bacteria which mimic the indicator species. Also, the narrower/shallower nature of the lake in the upper portion may permit shoreline influences and contributions of bacteria to have a relatively greater influence on observed levels at mid-lake stations in the upper reach.

The major source of indicator bacteria at Stations 1 and 2 is the inflowing river water. FC and FS levels in the river at the Leader Bridge (Highway 21) during the summer study periods of 1984 and 1985 were similar to those observed at Stations 1 and 2 (see Figure 52). The South Saskatchewan River receives a substantial loading of municipal sewage effluents via the Bow and Old Man Rivers from communities in Alberta. As such, the bacteriological quality of the river and upper portions of Lake Diefenbaker may be subject to moderate influences from upstream discharges. Generally, however, these influences have not been of a magnitude sufficient to impair lake water usage in Saskatchewan.

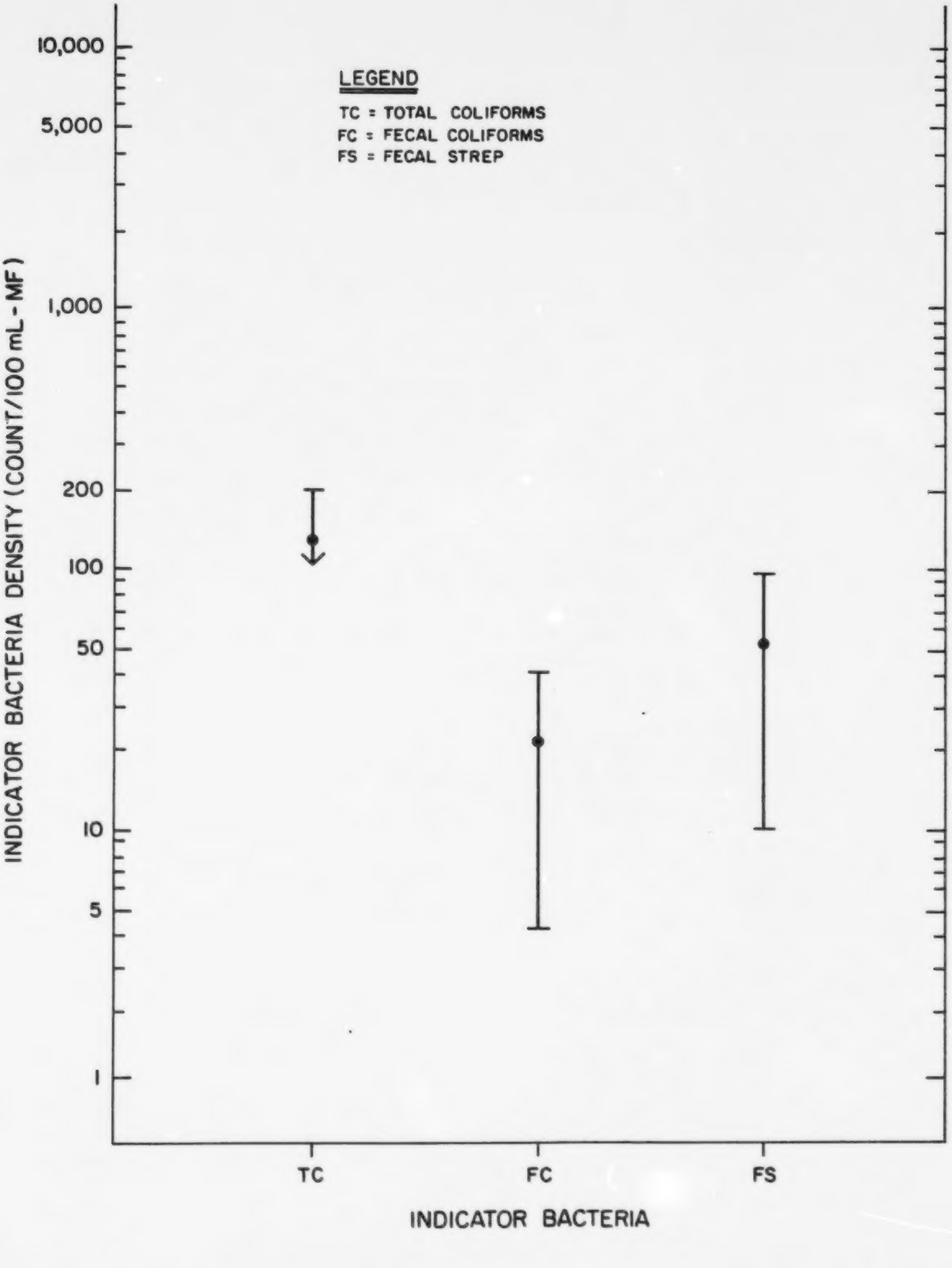


Figure 52 : INDICATOR BACTERIA (TC, FC, FS) DENSITIES AT LEADER BRIDGE (HWY. 21) ON THE SOUTH SASKATCHEWAN RIVER DURING SUMMER PERIODS OF 1984 - 1985

7. NEAR-SHORE STUDY

7.1 Assessment Methodology

7.1.1 Sampling Sites

All the primary sampling stations on Lake Diefenbaker are mid-lake stations which, ideally, will indicate the water quality of the main body and the major arms of the lake. Yet, a number of organisms such as phytoplankton and bacteria, and substances such as nutrients and dissolved oxygen may be more concentrated near the shoreline, downstream of minor discharges, and in shallow protected bays. The primary stations may, therefore, consistently over or under-estimate levels of these constituents. Some uses such as direct contact recreation, agriculture and wildlife, are particularly dependent on near-shore quality.

The five near-shore sampling stations selected for the Lake Diefenbaker Study are listed in Table 30.

Table 30

Lake Diefenbaker Near-Shore Sampling Sites - August, 1984

Station No.	Name
7.	Saskatchewan Landing Provincial Park Beach
8.	Opposite mouth of Swift Current Creek
9.	Hitchcock Bay
10.	Coteau Beach Subdivision
11.	Danielson Provincial Park Beach

7.1.2 Sampling Schedule and Field Methods

The main objective of the near-shore study was to identify constituents that may affect water quality for the near-shore uses mentioned. Since the maximum levels of parameters affecting the various uses would most likely occur in mid-summer, the study was undertaken during the week of August 13, 1984.

The sampling stations were picked for maximum weed growth, maximum blue-green algal growth, maximum direct contact uses, or maximum effect of stream discharges. A random sampling design was incorporated in the near-shore study, using a 30 by 100 metre grid and the selection of random numbers to determine the collection sites.

7.1.3 Parameters

In assessing the quality of Lake Diefenbaker in the near-shore areas, the parameters of greatest significance related to present uses of the water are bacteria and phytoplankton. The parameter list also included those constituents relevant to bacterial and algal growth, specifically the nutrients nitrogen and phosphorus, as well as diurnal changes in dissolved oxygen and temperature.

7.2 Results and Discussion

7.2.1 Field Measurements

Monitoring for the near-shore study included field measurements for dissolved oxygen (DO), temperature, pH, conductivity and secchi depth every time a sample was collected. Mean values for these parameters are shown in Table 31.

DO levels were satisfactory at all locations. The next section provides some additional information related to continuous monitoring of DO and temperature at a selected near-shore site. Temperature, pH and conductivity values were similar to measurements take at the nearby mid-lake stations and fell within the expected ranges.

Table 31

Lake Diefenbaker Near Shore Study Field Measurements - August, 1984

		Field Tests (means)				
Station	Date	D.O.(mg/l)	Temp (°C)	pH	Cond.	Secchi Depth (m)
Station 7	13-8-84	8.8	24.2	8.5	400	0.4
Station 8	14-8-84	8.5	21.8	8.7	454	0.8
Station 9	15-8-84	8.6	20.4	8.6	400	3.0
Station 10	14-8-84	9.7	22.0	8.6	405	0.4
Station 11	14-8-84	9.2	20.0	8.5	400	1.1

Low mean secchi depth readings at Stations 7, 8 and 10 are more likely a reflection of increased turbidity from wave action near shore rather than an increase in algal productivity. The value of 1.1 metres at Station 11 approximates the total depth at that site.

For the Lake Diefenbaker water quality study, an attempt was made to obtain continuous DO and temperature records from one station during the week of the near-shore survey, August 13, 1984. However, a short in one of the probe cables resulted in a malfunction of the recorder unit and no data was obtained.

Due to time constraints experienced during the summer of 1984 the equipment was set up at Station No. 9 - Hitchcock Bay - during summer, 1985, following the completion of other monitoring for the lake study. Figure 53 shows that little variation in DO concentration and temperature occurred over the 46 hour period of record. Wave action along the lake shoreline likely accounted for some aeration of the water, thereby stabilizing diurnal DO levels.

7.2.2 Nutrients

Five replicate samples were collected from each near-shore sampling location for the nutrient parameters of greatest significance - nitrate, ammonia, dissolved and particulate nitrogen, total phosphorus and dissolved phosphorus.

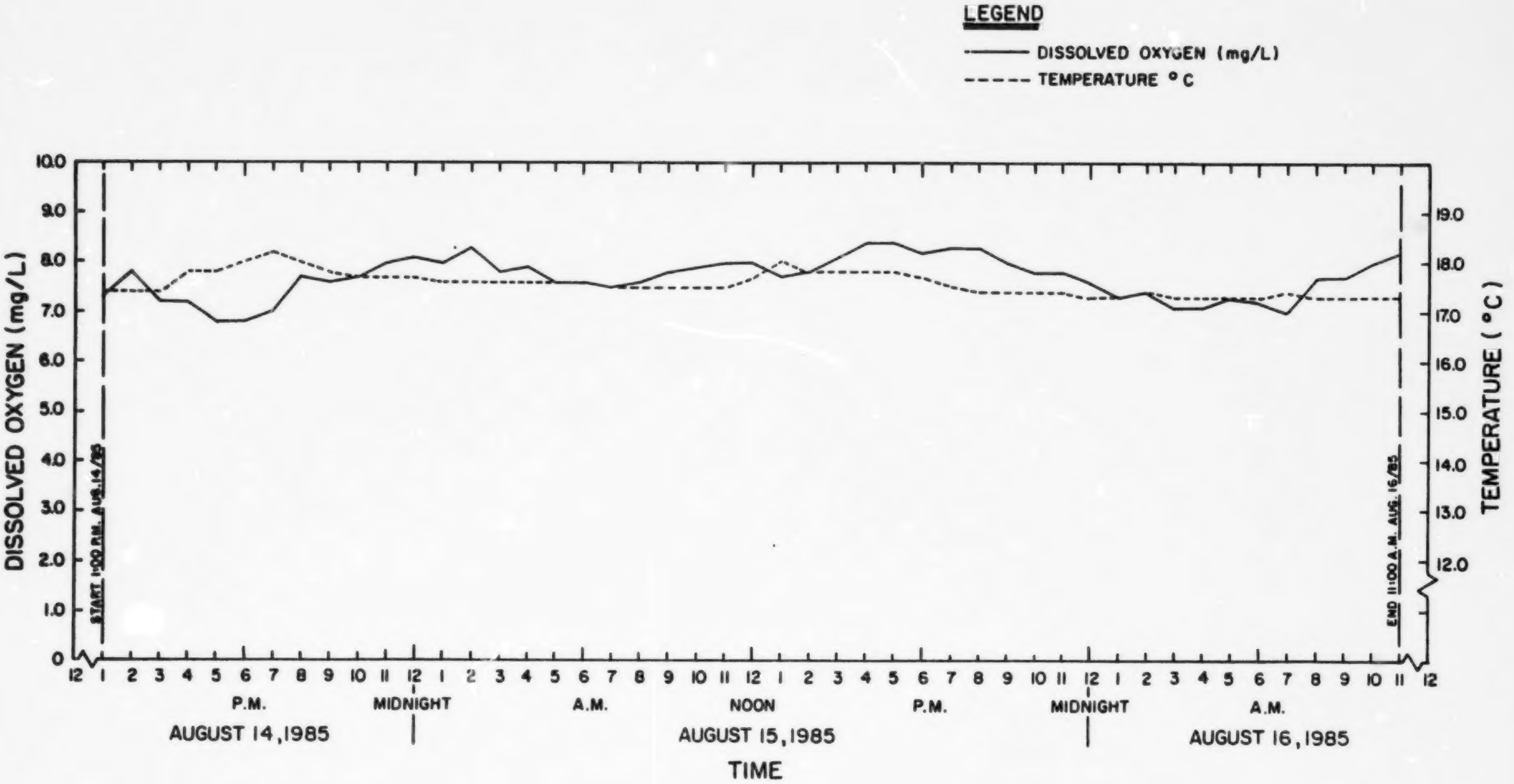


Figure 53: DIURNAL DISSOLVED OXYGEN CONCENTRATION (mg/L) AND TEMPERATURE (°C) AT LAKE DIEFENBAKER (STATION No. 9) AUGUST 14 - 16, 1985 (AS INDICATED BY CONTINUOUS D.O. RECORDER)

Nitrogen

Table 32 shows mean values for the major nitrogenous fractions analyzed at the near-shore locations.

Table 32

Mean Values for Nitrogen Parameters Analyzed for the Lake Diefenbaker Near-Shore Study - August, 1984

	Mean Nitrogen Values (mg/L)			
Station	Nitrate (NO_3)	Ammonia (NH_3)	Dissolved Nitrogen (DN)	Particulate Nitrogen (PN)
No. 7	0.03	<0.1	0.23	0.12
No. 8	<0.01	<0.1	0.21	0.09
No. 9	<0.01	<0.1	0.18	0.05
No. 10	<0.01	<0.1	0.15	0.10
No. 11	—	—	0.06	0.06

< = less than

Mean nitrate-nitrogen (NO_3) values were very low at all near-shore stations. This is to be expected since NO_3 is assimilated by algae and aquatic plants in the trophogenic zone (the stratum in which photosynthetic production occurs).

Similarly, ammonia nitrogen (NH_3) is usually present in low (less than 0.1 mg/L) quantities in non-polluted well oxygenated water. Results for the Lake Diefenbaker near-shore study indicate low concentrations of NH_3 at the time of sampling.

Mean values for dissolved nitrogen (DN) and particulate nitrogen (PN) ranged from 0.06 mg/L to 0.23 mg/L and 0.06 mg/L to 0.12 mg/L, respectively. The ratios of DN to PN decrease in summer in the near-shore zone, approaching 1:1. Table 32 shows lower mean DN and PN values at the near-shore stations as compared to the mid-lake locations for the same sampling period. DN and PN values also declined in a downstream direction, similar to the pattern exhibited by the nutrients in the mid-lake region.

Phosphorus

Table 33 illustrates the mean phosphorus values for Lake Diefenbaker during the near-shore study.

Table 33

Mean Values for Phosphorus Parameters Analyzed for the Lake Diefenbaker Near-Shore Study - August, 1984

	Mean Phosphorus Values (mg/L)		
Station	Total Phosphorus (TP)	Ortho-Phosphorus (Ortho-P)	Dissolved Phosphorus (DP)
No. 7	0.032	<0.003	0.010
No. 8	0.028	<0.003	0.016
No. 9	0.018	<0.003	0.006
No. 10	0.034	<0.003	0.003
No. 11	0.008	<0.003	<0.003

< = less than

Mean TP values for the Lake Diefenbaker near-shore study ranged from 0.008 mg/L to 0.032 mg/L, well below the Saskatchewan surface water quality objective for TP of 0.05 mg/L. Low phosphorus input levels and the utilization of phosphorus by macrophytic and phytoplankton growth during the summer months probably accounts for the reduced phosphorus levels experienced at the near-shore stations during August, 1984.

Mean dissolved phosphorus (DP) values were low at the time of sampling. This reflects an increased uptake of phosphorus by algae and aquatic plants during the summer period. Most of the phosphorus at this time of year is associated with aquatic plants and would be measured as TP. As the littoral macrophytes and attached algae decay phosphorus will be released to the open water.

7.2.3 Phytoplankton

Phytoplankton growth dynamics were studied at the five Lake Diefenbaker near-shore locations. The purpose of this investigation was to identify whether significant variations in algal biovolume and species composition exist between the mid-lake stations and near-shore regions. Note that the phytoplankton component of the near-shore study consisted of a single day of sampling data and therefore seasonal comparisons with primary stations is limited to the single August 13-15, 1984 survey period.

A total of 81 algal taxa were identified at the five near-shore stations (see Table 34). These 81 taxa represented 58 phytoplankton genera. This compared with 108 species and 68 genera observed at the primary sampling stations 1-6 during the July, 1984-June, 1985 study period. The reduced number of algae species noted during the near-shore survey was most likely a reflection of the single day sampling period.

The lower number of algae species also indicates that species abundance and composition varies considerably on a seasonal basis as was noted in Section 6.1. Total overall species abundance at mid-lake stations, during the August 13-15, 1984 survey period was only 69 spp. (see Figure 44). This dismisses the possibility that the lower overall species abundance (81 spp.) observed during the near-shore study was actually due to lower species richness in the near-shore areas. Instead, comparisons for the August 13-15, 1984 survey period indicate that total species diversity at near-shore locations was actually higher than that at mid-lake.

The pattern of overall species numbers represented by various phylums was essentially unchanged from that noted at the mid-lake stations. The greatest abundance (37 spp.) occurred within the phylum Chlorophyta (green

Table 34

Phytoplankton Genera and Species Observed in Lake Diefenbaker Near-Shore Study - August, 1984 (n = 81).

CHLOROPHYTA (n = 37)
(Green Algae)

Actinastrum gracilimum
Ankistrodesmus falcatus
Cladophora fracta
Closterium sp.
Coelastrum cambricum
C. microporum
Cosmarium sp.
Crucigenia apiculata
C. quadrata
C. tetrapedia
Dictyosphaerium pulchellum
D. simplex
Elaktothrix gelatinosa
Evastrum sp.
Eudorina elegans
Gonium pectorale
G. sociale
Kirchneriella lunaris
K. obesa
Lagerheimia sp.
L. quadriseta
Monoraphidium contortum
Oocystis borgei
O. gigas
O. solitaria
Pandorina morum
Pediastrum boryanum
P. duplex
P. obtusum
P. simplex
P. tetras
Quadrigula chodatii
Scenedesmus acuminatus
S. arcuatus
S. bijuga
S. ecornis
S. quadricauda
Selenastrum gracile
Staurastrum sp.

CYANOPHYTA (n = 12)
(Blue-green Algae)

Anabaena flos-aquae
Aphanizomenon flos-aquae
Aphanocapsa sp.
Aphanothece sp.
Chroococcus dispersus
C. limneticus
Coelosphaerium naegelianum
Gomphosphaeria aponina
Merismopedia glauca
Microcystis aeruginosa
Oscillatoria tenius
Spirulina sp.

BACILLARIOPHYTA (n = 22)
(Diatoms)

Asterionella formosa
Cocconeis pediculus
Cymatopleura sp.
Cymbella sp.
Diatoma sp.
D. elongatum
Fragilaria crotonensis
Gomphonema sp.
Gyrosigma sp.
Melosira granulata
Meridion circulare
Navicula sp.
N. oblonga
Nitzschia sp.
N. acicularis
Rhopalodia gibba
Stauroneis sp.
Stephanodiscus astrea
Synedra acus
S. ulna
Tabellaria fenestrata
Tropidoneis sp.

Table 34 (continued)

Phytoplankton Genera and Species Observed in Lake Diefenbaker Near-Shore Study - August, 1984 (n = 81).

CHRYSOPHYTA (n = 4)
(yellow-green algae)

Dinobryon sertularia
D. sociale
Mallomonas acaroides
Synura uvella

EUGLENOPHYTA (n = 2)
(Euglenoids)

Euglena sp.
Phacus sp.

PYRRHOPHYTA (n = 4)
(Dinoflagellates)

Ceratium hirundinella
Cryptomonas sp.
Symnodinium sp.
Peridinium sp.

algae). The phyla Bacillariophyta (diatoms) and Cyanophyta (blue-green algae) remained second and third with 22 and 12 species respectively. Euglenophyta (Euglenoids) was least abundant, accounting for only two species (see Table 34).

Spatial trends regarding species abundance are summarized in Table 35. As with mid-lake stations, Chlorophyta was the most diverse phylum at all near-shore stations. The highest total species abundance (54 spp) occurred at near-shore Station 7. This station is in relatively close proximity to mid-lake Station 2 which correspondingly had the highest species abundance among mid-lake stations. Near-shore species abundance was lowest at Station 11 (Danielson).

Table 35

Total Number[1] of Phytoplankton Species Observed Within Each Phylum at Each Near-Shore Sampling Station in Lake Diefenbaker - August, 1984.

	Sampling Station Number				
Phylum	7	8	9	10	11
Bacillariophyta	11 (20)	15 (28)	9 (18)	18 (34)	12 (25)
Chlorophyta	29 (54)	24 (45)	23 (46)	20 (38)	21 (44)
Chrysophyta	2 (4)	2 (4)	4 (8)	3 (6)	3 (6)
Cyanophyta	8 (15)	7 (13)	9 (18)	7 (13)	7 (15)
Euglenophyta	2 (4)	2 (4)	1 (2)	2 (4)	2 (4)
Pyrrhophyta	2 (4)	3 (6)	4 (8)	3 (6)	3 (6)
Total No. Species	54	53	50	53	48
Rank	1	2	3	2	4

[1] Brackets indicate the proportion of the total number of algal species observed at that sampling station.

The total relative volumetric composition of phytoplankton phyla at each near-shore station is presented in Table 36.

Total mean biovolume was highest at Station 9 and lowest at Station 7. This is generally consistent with spatial trends noted at mid-lake stations (see Section 6.1). Overall mean algal biovolume (all stations combined) was 16% lower at near-shore sites than at mid-lake.

The slightly higher species abundance and lower mean algal biovolume at near-shore stations during mid-August, 1984 suggest subtle differences between near-shore and

Table 36

Total Relative (per cent) Volumetric Composition of Phytoplankton Phyla at Each Near-Shore Station in Lake Diefenbaker - August 13-15, 1984.

	Sampling Station Number				
Phylum	7	8	9	10	11
Bacillariophyta	9	41	1	12	4
Chlorophyta	12	10	7	7	8
Chrysophyta	11	6	9	3	11
Cyanophyta	64	30	81	74	72
Euglenophyta	1	N	N	N	N
Pyrrhophyta	3	13	2	4	5

N - Negligible

mid-lake algal growth dynamics. Near-shore populations may be more variable or less stable due to effects of wind blown accumulation in bays and more active mixing currents along shore due to wave action. Reduced sample numbers during the near-shore study also would be a source of variability. Spatial trends regarding algal biovolume and composition appears to be quite similar between near-shore and mid-lake regions of Lake Diefenbaker.

7.2.4 Bacteria

On Lake Diefenbaker, as on many other lakes in Southern Saskatchewan, contact and non-contact recreation is an important and significant water use. The demand for water based recreation on the lake is expected to increase with increased developments around the lake.

Although widely used year-round for non-contact recreation (e.g. boating, fishing) beach areas of Lake Diefenbaker are utilized for recreational bathing mainly during the summer season.

High densities of bathers at popular bathing beaches may contribute significantly to at least short-term increases in the levels of indicator bacteria in near-shore waters. Wind action, resulting in the resuspension of in-shore sediments and detritus, may have a similar influence on the near-shore bacteriological quality. Also, high densities of cattle or other livestock and wildlife with access to the lakeshore may contribute directly or indirectly to increases in indicator bacteria levels in near-shore waters. Lastly, shallow, sheltered bays along lakeshores may be subject to higher summer ambient temperatures and to greater rates of accumulation of organic matter which may be conducive to the growth and survival of indicator bacteria of fecal and non-fecal origin.

In the present study the bacteriological quality of near-shore waters was examined at five locations during the main contact-recreational period of summer, 1984. The results of total and fecal coliform (TC, FC) and fecal streptococci (FS) bacteria determinations at these five sites have been summarized in Figures 54, 55 and 56, respectively.

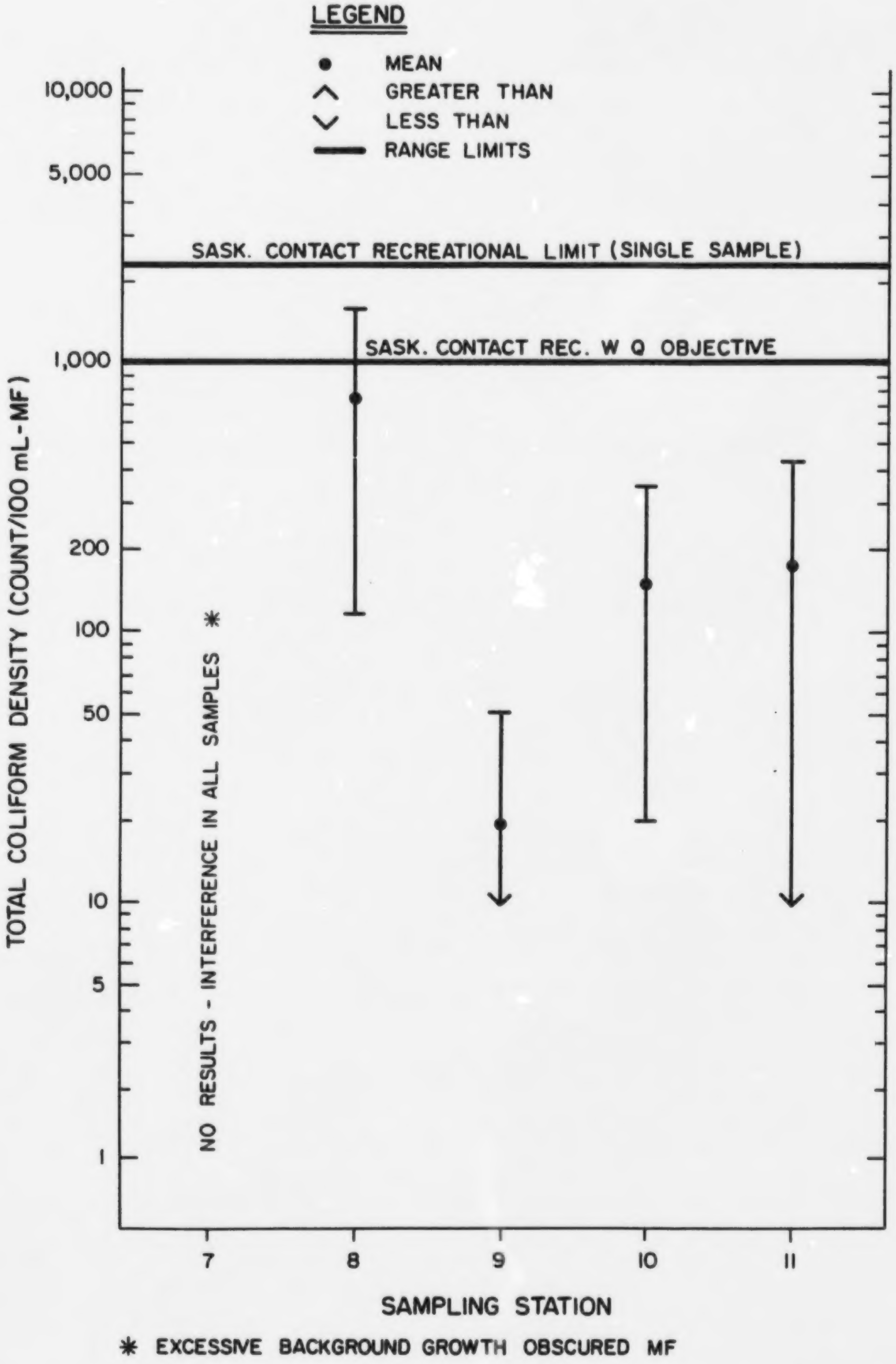


Figure 54: TOTAL COLIFORM DENSITIES AT NEAR-SHORE STATIONS ON LAKE DIEFENBAKER - AUGUST 13-15, 1984

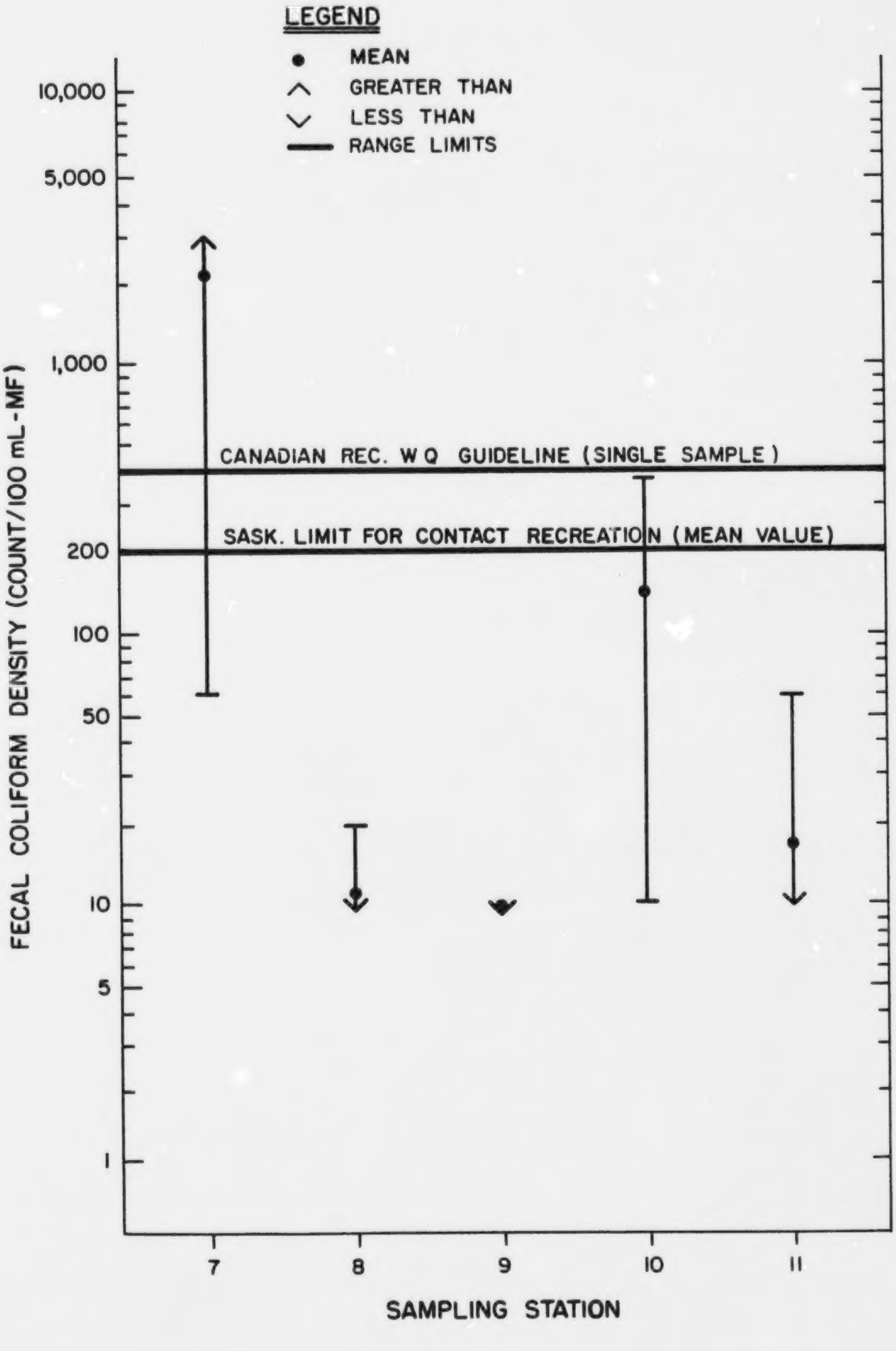


Figure 55 : FECAL COLIFORM DENSITIES AT NEAR-SHORE STATIONS ON LAKE DIEFENBAKER - AUGUST 13-15, 1984

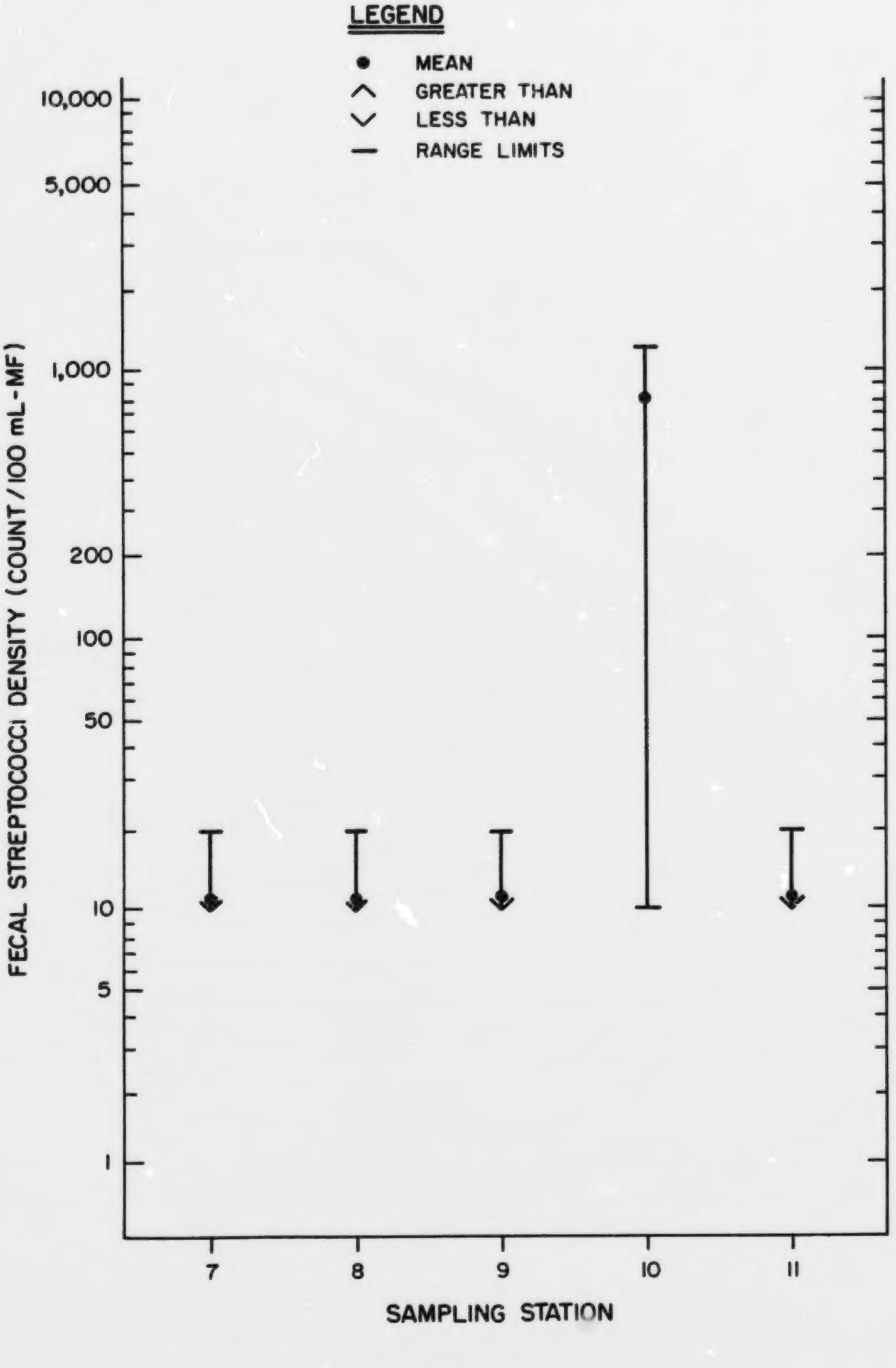


Figure 56 : FECAL STREPTOCOCCI DENSITIES AT NEAR-SHORE STATIONS ON LAKE DIEFENBAKER AUGUST 13 - 15, 1984

It should be noted that during the three-day period (August 13-15, 1984) in which the bacteriological sampling of near-shore locations was conducted moderate (5-25 Km per hour) winds were recorded during sampling on August 13 and 15, 1984. High winds (up to 70 Km per hour) were recorded for August 14, 1984. Wind and wave action, particularly on August 14 reportedly made sampling of the study site very difficult and may have had a detrimental influence upon the bacteriological quality of the near-shore waters as will be discussed below.

The relatively shallow shoreline waters at Station 7, adjacent to the Saskatchewan Landing beach area, were sampled August 13, 1984. Moderate turbidity and algae levels were recorded for the sampling sites. Total coliform levels (Figure 54) could not be determined during analyses due to excessive bacteria colony counts obscuring the observation of TC bacteria. Such interferences in TC results are not uncommon with the TC analytical procedures. Interference due to high levels of non-coliform bacteria prevents determination of the target indicator TC bacteria, but this phenomenon in itself may suggest water quality impairment.

Fecal coliform densities in the 10 samples collected at Station 7 ranged from 60 to 63,000 FC/100 ml. The mean FC density was 2,120 FC/100 ml, much higher than the surface water quality objective (200 FC/100 ml) pertaining to contact recreational use of the water (Saskatchewan Environment, 1983). The cause of the relatively high FC levels at this site is uncertain, but coincidentally low levels of fecal streptococci (e.g. <10-20 FS/100 ml, Figure 56) suggest the FC results were not related to any recent contamination of the shore water with human or animal feces. It is probable that these observations related to the detection of bacteria such as Klebsiella spp. which may be associated with decaying plant material resuspended by wind-induced turbulence in the shoreline areas. Water depths at this site ranged from only 1.0-2.2 m. In such instances, high FC levels may be recorded even though the bacteria enumerated are not of fecal origin, as the name of this indicator group would suggest. Such results are of uncertain water quality significance. Further monitoring of this shoreline location would be required to accurately define the bacteriological quality of the water and to determine the actual cause(s) of the results obtained in the August 13, 1984 survey.

Near-shore Stations 8, 10 and 11 were surveyed on August 14, 1986 when high winds were recorded throughout the day. At Station 8, at the mouth of Swift Current Creek, moderate levels of TC bacteria (range 120 to 1600 TC/100 ml) were determined. However, very low levels of both FC and FS were observed at this site (Figures 55, and 56). The bacteriological water quality at this location was suitable for contact recreation and for all other uses addressed in the provincial surface water quality objectives (Saskatchewan Environment, 1983). The sheltered sampling location and relatively deeper water (e.g. 4-5 m) may have reduced any potential influence of wave action impacting significantly upon the bacteriological quality of water at this site.

At near-shore Station 10, near the Coteau Beach subdivision, the bacteria densities in the relatively shallow water (e.g. 0.7-2.0 m) were similar for the TC and FC indicator groups determined. The coincidentally high FS densities (e.g. mean of 887 FS/100 mL) indicate contamination of the water with fecal material most probably of animal origin. Cattle were observed watering along portions of the nearby shoreline. In addition, the surrounding land is drained by an intermittent stream which flows into the small bay in which the samples were obtained. The surrounding land is also partially developed for residential/cottage dwelling.

Although wind action on the day Station 10 was surveyed may have been a major factor influencing the relatively poor bacteriological quality of the water, the results also suggest that significant quantities of fecal material may be entering the small bay from livestock and through human activities/land use practices (e.g. drainage, septic systems) along the shoreline. On the survey date the mean FC level was just below the acceptable limit for contact recreational use of the water (e.g. Saskatchewan Environment, 1983; Health & Welfare Canada, 1983). These results, together with the FS data, suggest the recreational potential of the near-shore water at this site may be in jeopardy. Further study of this location is warranted.

The bacteriological quality at Station 11, adjacent to the Danielson Provincial Park beach, was relatively good and characterized by low levels of both FC and FS. Although a relatively shallow area (e.g. 1.0-1.4 m deep), wave action combined with a sandy, weed-free bottom probably prevents accumulation of organic debris along the shoreline. These factors may have accounted for the relatively good bacteriological quality of this location despite the high degree of wind-induced turbulence on the day of sampling. At this location TC and FC levels were both well below respective limits concerning all water uses addressed in the existing surface water quality objectives (Saskatchewan Environment, 1983).

Finally, near-shore Station 9, across the mouth of Hitchcock Bay, was sampled on August 15, 1984, under moderately strong wind conditions. Water depth at this site ranged from 10-14 m, indicating wind action would likely have little influence on bacteriological quality of the water.

As can be seen in the bacteriological results (Figures 54, 55, and 56) only very low levels of all three indicator groups were recorded for this site. In these regards, the water quality at this location was similar to that of the nearby mid-lake Station 4 (Figures 49, 50 and 51). As such the bacteriological quality at Station 9 is suitable for all uses addressed in the current surface water quality objectives (Saskatchewan Environment, 1983).

The results of bacteriological surveys conducted at near-shore locations indicate potential water quality impairment at two of the areas examined - Saskatchewan Landing and Coteau Beach. Although the results are based upon a single-day survey and may have been detrimentally influenced by weather conditions at the time of sampling, the findings suggest a need for additional bacteriological monitoring at these two locations. Only in this manner can causal influences be determined and effective mitigative measures undertaken.

8. CONCLUSIONS AND RECOMMENDATIONS

The Lake Diefenbaker and Upper South Saskatchewan River Water Quality Study, 1984-85, was designed to provide a reliable information base for water managers responsible for the long-term protection of these waterbodies.

The study results were assessed in terms of the Saskatchewan Surface Water Quality Objectives and other water quality criteria. Overall, the results indicate that the water quality of Lake Diefenbaker and the Saskatchewan portion of the upper South Saskatchewan River is satisfactory for the present and expected uses of the water. More specific conclusions and some recommendations for future investigation are provided as follows:

8.1 Hydrology

- The period during which this study was undertaken - July, 1984 to June, 1985 - occurred in the middle of a relatively severe drought in western Canada. Reduced flows in the South Saskatchewan and Red Deer Rivers resulted in extensive drawdown of Lake Diefenbaker during 1984-85.

- Lake levels in 1984 were the lowest since 1969 for the months of August through November - as much as 8 metres below full supply level.

- The comparability of the observations made from the 1984-85 study must therefore be considered in a limiting context until such time as similar work can be carried out under more typical hydrologic conditions.

8.2 River Chemistry

- Dissolved nitrogen was the dominant nitrogen form at Lemsford Ferry throughout the fall and winter seasons and was dominant at Gardiner throughout the year.

- Concentrations of total nitrogen at Lemsford exceeded the Saskatchewan water quality objective of 1.0 mg/L throughout the winter, into the spring and occasionally during the fall as well, while at the Gardiner site total nitrogen concentrations in 1985 were well below the objective.

- Phosphorus at Lemsford was predominantly of the particulate form. The correspondence between total phosphorus and total suspended solids was evident at this site. In contrast to Lemsford, dissolved phosphorus was the dominant form throughout much of the year at Gardiner.

- Total phosphorus results at Lemsford exceeded the Saskatchewan surface water quality objective of 0.05 mg/L on numerous occasions during the study period while no exceedences of the provincial objective were recorded at the Gardiner site. Total phosphorus at Gardiner was approximately an order of magnitude less than the concentration at Lemsford.

- It is recommended that monitoring of the outflow chemistry at Gardiner Dam be continued to better understand the nutrient cycling in that part of Lake Diefenbaker.

- The long-term monthly monitoring data showed that total phosphorus loading into Lake Diefenbaker was quite variable from year to year, ranging from 247 tonnes (1984) to 2077 tonnes per annum (1980). The mean annual phosphorus load into the lake (1975-1985) was 1229 tonnes. Of the two tributary sources, the main stem South Saskatchewan River tended to contribute slightly more total phosphorus load than the Red Deer River.

- Dissolved phosphorus loading into Lake Diefenbaker varied less from year to year than TP, ranging from 40 tonnes (1984) to 199 tonnes (1980), and with a 1978-1985 mean of 121 tonnes per annum. The South Saskatchewan contribution of DP exceeded that of the Red Deer River throughout the period.

- The long-term dissolved phosphorus/total phosphorus percentages showed that approximately 89% of the TP load entering Lake Diefenbaker annually was of the particulate phosphorus fraction.

- The determination of biologically available phosphorus in the suspended sediments of the South Saskatchewan and Red Deer Rivers should be an area for future study.

- It is recommended that sampling frequency be increased to weekly or bi-weekly during the April-July period to provide more accurate TP loading calculations. The frequency of TP sampling could be reduced to bi-monthly during the October-February period with little loss in accuracy.

- The intensive monitoring program conducted at Lemsford Ferry in 1985 produced a total phosphorus loading figure of 814 tonnes/annum. The 1985 dissolved phosphorus loading based on Lemsford Ferry was 73 tonnes. These values compare quite closely with the phosphorus loading contributed by the tributaries, and it is probable that acceptable estimates of phosphorus loading into Lake Diefenbaker can be achieved at the South Saskatchewan and Red Deer River stations.

- Depending upon the level of accuracy required, the frequency of sampling will have to be altered to achieve better definition of major loading seasons, especially in years where above average discharge is anticipated.

- The study period data for major ions showed that the Red Deer River tends to be more highly mineralized than the South Saskatchewan River. However, little change in concentration of major ions occurred in the 330 kilometre reach between Leader and Outlook, which includes Lake Diefenbaker.

- The location of the precise point where the South Saskatchewan River becomes Lake Diefenbaker has long been argued. In terms of seasonal variations in major ion parameters, lake characteristics begin to outweigh river characteristics in the Saskatchewan Landing-Herbert Ferry reach.

- The linear nature of the seasonal trend curves for major ions at Outlook shows the impounding effects of Lake Diefenbaker, indicating that the waters of several seasons are mixed by the time they pass through Gardiner Dam.

- The major ion results indicate that there have been no exceedences in most sensitive use objectives and guidelines during the period of record. The likelihood of any exceedence, given the present patterns of use within Alberta and Saskatchewan, is low in the short or medium term.

8.3 Lake Chemistry

- The study period dissolved oxygen (DO) monitoring results for Lake Diefenbaker indicated that, for the most part, DO levels were better than the Saskatchewan surface water quality objective of 5.0 mg/L. The exceptions to this were some low levels experienced during summer stratification and under ice covered conditions. These were measured sporadically and in isolated portions of the lake, particularly at lower water depths and would not be considered a problem for fish and other aquatic life. Results for Lake Diefenbaker indicated that the oxygen levels quickly recovered during the spring and fall overturns.

- Although the nutrient concentrations measured during the study were quite low, Lake Diefenbaker was responding to some extent to the nutrient loads received from the South Saskatchewan River system. Nutrient levels were consistently higher at the shallower upstream sample locations than in the deep water areas. The fact that Lake Diefenbaker is acting as a sink for nutrients flowing in from the South Saskatchewan River is evident by the very low levels measured at the outflow from Gardiner Dam.

- Seasonal cycling of nutrients in Lake Diefenbaker was also evident with higher levels of total nitrogen and phosphorus present in spring and early summer and higher levels of dissolved (bioavailable) constituents in winter.

- The mean annual chlorophyll "a" levels reported for Lake Diefenbaker indicated a change in trophic status from mesotrophic (moderately enriched) in the vicinity of Station 2 to oligotrophic (low in nutrients) in the lower reaches.

- It is recommended that the chlorophyll "a" sampling procedure be reviewed with the intention of limiting sample collection to the photic zone.

8.4 Eutrophication

- Using the inorganic nitrogen/ortho-phosphate ratios (N:P) it was determined that the growth of algae in Lake Diefenbaker is phosphorus limited (i.e. an increase in the lake concentration of phosphorus will cause a proportional increase in the algal productivity). Therefore, the Vollenweider (1976), OECD (1982) water quality modelling approach was considered to be applicable to Lake Diefenbaker.

- The length and shape of Lake Diefenbaker and the consideration of only the "river input" loadings resulted in splitting the lake into five sections for the purpose of the model.

- Using the OECD (1982) graphs and the mean annual phosphorus, chlorophyll "a" and secchi depths the trophic status of Lake Diefenbaker was determined. This analysis indicated that the Saskatchewan Landing area of the lake was mesotrophic. It was felt that, at least for the present model, maintaining the phosphorus in the Saskatchewan Landing area of the lake at an average summer concentration of less than 20 mg/m^3 would maintain the trophic status of the lake at mesotrophic or better (i.e. [chl a] <3 mg/m^3).

- Further data should be collected on the five lake areas and the inlet to the lake to refine the relationship of phosphorus and chlorophyll "a" to trophic state. This data collection should be limited to the summer period (June, July and August) for the lake and monthly for the inlet to the lake.

- In view of the results of the 1984-85 study it would appear that the present phosphorus loading considered permissible by the PPWB (285 tonnes/year) is approximately twice as high as the level that would maintain the Saskatchewan Landing area of Lake Diefenbaker in a mesotrophic state.

- The present database for Lake Diefenbaker and the upper South Saskatchewan River should be augmented with at least three more years of data collection. When these additional data are available a complete review of the nutrient loading criteria at the Alberta border should take place.

- Further refinement of the OECD (1982) water quality model should include phosphorus loadings from all major sources including runoff from surrounding land and atmospheric deposition.

8.5 Lake Biology

- The spatial characteristics observed for the 1984-85 study regarding species composition and algal biovolume showed the trophic status of Lake Diefenbaker varied depending on location. The trophic status was mesotrophic in the upper half of the reservoir and became progressively more oligotrophic toward the downstream end. This was consistent with the findings based on chlorophyll "a" concentrations.

- Future monitoring of Lake Diefenbaker should include study of periphyton (attached algae) to better assess site-specific water quality effects on algal population dynamics.

- In Saskatchewan the bacteriological quality of surface waters is assessed using various objectives for the indicator bacteria, total and fecal coliforms. Overall, the results for the 1984-85 study indicated that the indicator bacteria densities reported for Lake Diefenbaker were within the surface water quality objectives for contact recreation and other identified uses.

- Future monitoring for bacteria should include more intensive sampling in shallow near-shore areas such as bathing beaches. This sampling should be conducted under favourable weather conditions to avoid the impact of high winds in the shallow water.

8.6 Near-Shore Study

- The diurnal dissolved oxygen monitoring done at Station 9 (Hitchcock Bay) showed that DO levels stayed relatively constant over the 46 hour period of record and were well above provincial water quality objectives. Wave action along the shoreline likely accounted for some reaeration of the water, stabilizing diurnal DO levels.

- Nutrient levels at all near-shore stations were low, probably indicative of increased uptake of bioavailable nutrients by aquatic plants and algae in the near-shore region.

- Spatial trends regarding algal biovolume and composition appeared to be quite similar between near-shore and mid-lake regions of Lake Diefenbaker. Near-shore populations were less stable due to effects of wind blown accumulation in bays and more active mixing currents along shore due to wave action.

- The bacteriological results obtained indicate satisfactory water quality at all near-shore stations except Stations 7 and 10, where there appears to have been some water quality impairment. However, the results are based upon a single day survey at each location and may have been detrimentally influenced by inclement weather conditions (high winds).

REFERENCES

Bierhuizen, J. F. H. and E. E. Prepas, 1985. Relationship between nutrients, dominant ions and phytoplankton standing crop in prairie saline lakes. Can. J. Fish. Aquat. Sci. 42:1588-1594.

Canadian Council of Resource and Environment Ministers (CCREM), 1987. Canadian Water Quality Guidelines.

Charlton, S., P. Cross, K. Exner, P. Grant, H. Hamilton and J. Stewart, 1981. South Saskatchewan River basin eutrophication control study. 1980-81 interim report. Water Quality Control Branch, Alberta Environment.

Cooke, G. Dennis, E. B. Welch, S. A. Peterson, P. R. Newroth, 1980. Lake and Reservoir Restoration. Butterworth Publishers, Stone Lake, Massachusetts.

Cole, G. A., 1979. Textbook of Limnology. The C.V. Mosby Company, St. Louis, Missouri.

Cross, P. M., H. R. Hamilton and S. E. D. Charlton, 1984 draft. The limnological characteristics of the Bow, Oldman and South Saskatchewan Rivers. I. Nutrient and Water Chemistry. Water Quality Control Branch, Alberta Environment.

Dillon, P. J. and W. B. Kirchner, 1975. The effects of geology and land use on the export of phosphorus from watersheds. Water Res. 9:135-148.

Environment Canada, 1973. Instructions for taking and shipping water samples for physical and chemical analysis. 2nd Ed. Water Quality Branch, Inland Waters Directorate, Ottawa, Ontario.

Environment Canada, 1979. Water Quality Sourcebook: A Guide to Water Quality Parameters. Water Quality Branch, Inland Waters Directorate, Ottawa, Ontario.

Environment Canada, 1983. Sampling for Water Quality. Water Quality Branch, Inland Waters Directorate, Ottawa, Ontario.

Environment Canada, 1985. Historical stream flow summary, Saskatchewan (to 1984). Water Resources Branch, Water Survey of Canada, Ottawa, Ontario.

Fruh, E. G., K. M. Stewart, G. F. Lee and G. A. Roblick, 1966. Measurement of eutrophication and trends. J. Water Poll. Control Fed., 38:1237-1257.

Green, R. H., 1979. Sampling design and statistical methods for environmental biologists. John Wiley and Sons, New York.

Hamilton, H. R., 1983 Draft. Application of water quality criteria to the South Saskatchewan River basin planning program. Pollution Control Division, Alberta Environment.

Hutchinson, G. E., 1967. A treatise on limnology, Vol. II. Introduction to lake biology and the limnoplankton. Wiley, New York.

Janus, L. L. and R. A. Vollenweider, 1981. The OECD co-operative programme on eutrophication, Canadian contribution. National Water Research Institute, Canadian Centre for Inland Waters, Burlington, Ontario. Scientific series No. 131.

Lund, J. W. G., 1969. Planktonic algae and the ecology of lakes. Sci. Prog. (Oxford). 55:401-419.

Lund, J. W. G., 1969. Phytoplankton in Eutrophication: Causes, Consequences, Correctives. Natl. Acad. Sci., Washington, pages 306-329.

Mueller, D. K., 1982. Mass-balance estimation of phosphorus concentrations in reservoirs. Water Res. Bull. 18:377-382.

OECD, 1982. Eutrophication of Waters: Monitoring, Assessment and Control. Organization for Economic Co-operation and Development, Paris, France.

Ongley, E. D. and D. P. Blachford, 1982. Nutrient and contaminant pathways in the Bow and Oldman Rivers, Alberta, 1980-1981. Department of Geography, Queen's University, Kingston.

Patrick, R., M. H. Hohn and J. H. Wallace, 1954. A new method for determining the pattern of the diatom flora. Notulae Nature Acad. Nat. Sci. Philadelphia.

Pollution from Land Use Activities Reference Group (PLUARG), 1978. Environmental Land Use Strategy for the Great Lakes Basin. Final Report to the International Joint Commission.

Prairie Provinces Water Board, 1987. Interprovincial river water quality data at PPWB monitoring stations, April, 1974 to December, 1985. Committee on Water Quality, PPWB, Regina.

PPWB, 1987. PPWB Water Quality Indicators for the South Saskatchewan River at the Alberta/Saskatchewan Boundary, Supporting Documentation. Draft December, 1987.

Rast, W. and G. F. Lee, 1978. Summary analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading - Lake Response relationships and trophic state indicators.

Richards, J. H. and. K. I. Fung, 1969. Atlas of Saskatchewan, University of Saskatchewan, Saskatoon.

Ryding, S. O., 1980. Monitoring of Inland Waters: OECD Eutrophication Programme, the Nordic Project. Nordforsk publication.

Saskatchewan Environment, 1980. Municipal Drinking Water Quality Objectives.

Saskatchewan Environment, 1983. Water Quality Objectives (3rd Printing). Water Pollution Control Branch, Regina.

Saskatchewan Environment, 1984a. Wascana Creek/Qu'Appelle River Bacteriological Water Quality - Summer, 1982. WPC 39.

Saskatchewan Environment, 1984. Water Quality Study, North Saskatchewan River - Prince Albert Area (Autumn, 1983). WPC 40.

Saskatchewan Environment, 1984. Water Pollution Control Branch Field Procedures Manual. Water Pollution Control Branch, Regina. August, 1984 revision.

Scavia, D. and S. C. Chapra, 1977. Comparison of an ecological model of Lake Ontario and phosphorus loading models. J. Fish Res. Board Can. 34:286-290.

Sonzogni, W. C., T. J. Monteith, W. N. Bach and V. G. Hughes, 1978. United States Great Lakes Tributary Loadings. Technical report of the Pollution from Land Use Activities Reference Group (PLUARG) of the International Joint Commission, Windsor.

South Saskatchewan River Basin Study News. November, 1986 issue. South Saskatchewan River Basin Study Office, Moose Jaw.

Stevenson, R. J. and R. L. Lowe, 1986. Sampling and interpretation of algal patterns for water quality assessments. Rationale for sampling and interpretation of ecological data in assessment of freshwater ecosystems, ASTM STP 894, B. G. ISOM, Ed., American Society for Testing and Materials, Philadelphia.

Stoker, H. Stephen, and S. L. Seager, 1976. Environmental Chemistry: Air and Water Pollution. Scott, Foresman and Company, Glenview, Illinois.

Tones, P. I., 1983. Regina-Moose Jaw water supply study. Phase 1. Water quality monitoring program. SRC publ. C-805-17-E-83. Saskatchewan Research Council, Saskatoon.

Tones, P. I., 1984. Detailed Design of the Lake Diefenbaker and Upper South Saskatchewan River Quality Study. SRC publ. E-901-15-E-84. Saskatchewan Research Council, Saskatoon.

Vollenweider, R. A., 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. 1st Ital. Introbiol. 33:53-83.

Wetzel, R. G., 1975. Limnology. W. B. Saunders Company, Philadelphia.

Woodvine, R. J., 1983. Hydrologic history of Lake Diefenbaker Proceedings. Prairie Hydrology, Canadian Water Resources Assoc., Annual Meeting, Saskatoon, Saskatchewan.